

The Use of the Aerophonoscope for Assessing Velo-Pharyngeal Incompetence and Therapeutic Decisions

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Abstract: Aerophonoscope is an ultra sensitive and original instrument for detecting nasal airflow and analysing the Velo-Pharyngeal Sphincter –VPS - movements. It reveals the aerodynamic function of the VPS, in the usual conditions of speaking and breathing. It has been created for patients with facial cleft, of 4 years old upwards, after primary surgery and during their growth, in a harmless, non-invasive way. There are several sorts of assessments of Velo-Pharyngeal Incompetence (VPI): from an anatomical point of view, a perceptive, acoustic, aerodynamic one. The Aerophonoscope belongs to the latter one. We know the difficulties to treat this pathology in the fields of surgery and speech therapy mostly because of misunderstanding VP physiology and physiopathology, which are complex. Then aerophonoscopy allows us to understand this complexity. So we are able to easily assess excessive Nasal Loss -NL- factors. The NL is linked mainly with a VPS persistent lack of closing, of course. But it varies according to its stiffness, tonicity, and its smaller and slower movements. The latters are according to each phoneme or syllable, and they have more or less speedy succession of the “phonological verbal chain”. So we aim at presenting this instrument that enables an aerodynamic assessment of the VPS precisely. We can analyse many characteristics of its pathological movements with different tests in our protocol (passive, active, effort, successive movements and so on) and show the results of about 652 individuals. These data contribute to guide therapeutic decisions, (choice of type of surgery, targets of rehabilitation), such as to restore the VPS physiology at the very most. Furthermore, it provides a pleasant and efficient means of rehabilitation of the VPS

Keywords: Aerophonoscope, Velo-Pharyngeal Sphincter, Aerodynamic Assessment, Nasal Loss, Surgical Decisions, Visual Feed-Back for Rehabilitation

1. Introduction

Velopharyngeal incompetence is divided into 2 groups:

- 1) Closed rhinolalia which excludes the contribution of nasal resonance cavities, and so induces hypo-nasality, which is not dealt with in our study.
- 2) Open rhinolalia which, on the contrary, induces hypernasality and has different etiologies. Mainly, we can differentiate between:
 - a) Major dysmorphic damage (bony and soft cleft palate), treated early with primary surgery, but the incompetence may persist, requiring secondary surgery of the velopharyngeal neosphincter.

b) Minor rhinolalia, discovered at the age of about 2 to 5 years old in the context of speech delay, especially with genetic etiology +/- accompanied with hearing, psychological, neuropraxic and cognitive disorders.

The word “rhinolalia” usually means only acoustic and phonetic data, but in this study, we shall use the aggregate term, “velopharyngeal incompetence” from different aspects, aerodynamic, acoustic, phonetic and anatomic ones.

Among the present means, the AERO-D aerophonoscope enables the examination of velopharyngeal aerodynamic function in physiological conditions of speaking and breathing, without intimidation.

With a cohort of 652 subjects, it enabled us to discover different types of velopharyngeal incompetence and led us to

choose the best surgical and rehabilitation treatments, and to assess the effectiveness of these treatments. In French, the opposition between oral and nasal phonemes is important.

It opens up new research perspectives.

2. Method and Material

Equipment: The aerophonoscope was created in Nantes in the 1980's, by a speech therapist named Brother Pascal Rineau [1] and Professor Jean Delaire [2], who was a maxillo-facial surgeon. It can record nasal and oral air flow, by using original sensors in the physiological conditions of speaking and breathing without scaring the child, and is thus easy for children from 3 and a half to 4 years old. It may be used with a laryngeal microphone.

This equipment is composed of 3 sensors connected by a USB port to a computer, on which the AERO RD program has been installed. These sensors have thermistors, which are platinum wires, heated to 100°C by an electric current, and cooled by the air expired by the patient: the air flow cools the hot wires according to its speed.



Figure 1. Aerophonoscope sensors.

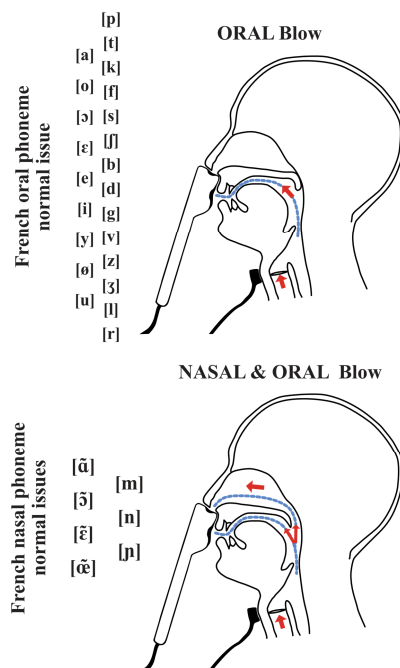


Figure 2. Aerophonoscope procedure.

Thus, even minimal nasal air loss can be quickly and

reliably detected for a given group of phonemes or syllables and their sequences, according to the physiological conditions of speech. This ultra-sensitive detection is easily reproducible. [31]

The mouth sensor is placed at a distance from the lips so as not to prevent them from moving spontaneously, therefore it can only detect a part of the buccal air flow, which is impossible to measure precisely in children.

The nasal air flow sensor matches the shape of nostrils as closely as possible.

It allows a sensitive and objective record of nasal air flow (NAF) and therefore shows 4 physiological facts:

- 1) spontaneous nasal ventilation (at rest, in speech or whistling),
- 2) the detection of any variations of Nasal Air Flow in speech; (Marshall [3])
- 3) Characteristics of closing/opening movements of the velopharyngeal sphincter (VPS) all through the alternate sequences of oral/nasal syllables: their closing competences, their amplitude and stiffness, their speed, their steadiness (according to accelerations, prosody of speech, etc.),
- 4) Voice-velum coordination, during the pronunciation of voiced or unvoiced consonants. The latter notions are the topic of another study.

These nasal and oral air flows are shown with 2 proceedings:

2.1. A Screen with a Child's Face

Whose nasal and buccal ports are colored.

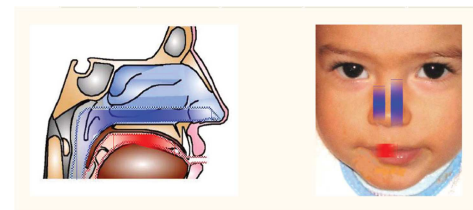
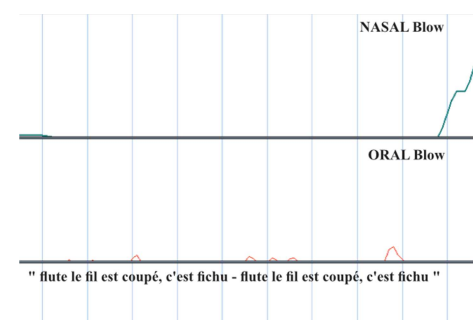


Figure 3. Continuous oral blow, with abnormal nasal loss.

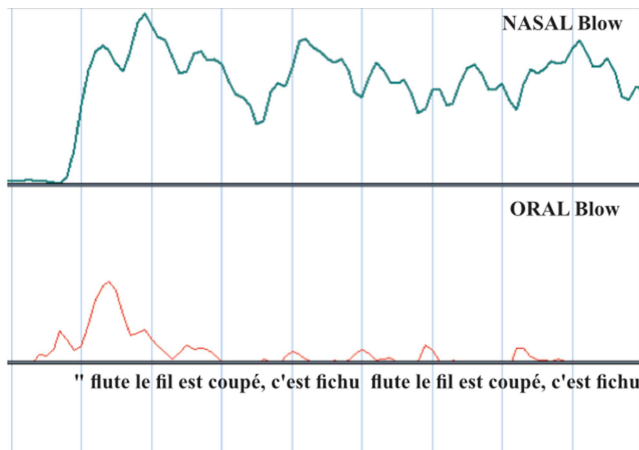
2.2. A Screen with 2 Main Lines

An upper one, for the nasal airflow, and a lower one, for the buccal air flow,—which is partially detected and so not interesting—or for the laryngeal tune. 2 vertical lines represent 1 sec.



No nasal loss for a sentence composed of oral sounds, in French.

a. Normal curve.



Nasal loss during the same sentence

b. Pathological curve.

Figure 4. Normal and pathological nasal blow curves by oral sounds.

On this curve we must observe the alternate rise and fall of the nasal flow line, linked with the up and down movements of the velum, linked to the sequences of Nasal syllables/Oral

syllables:

Here the nasal line shows:

- 1) The complete velopharyngeal closing, when the curve joins the base line on /a/.
- 2) the maximal amplitude of velopharyngeal opening during the ascendant peaks on the nasal syllable /non/
- 3) the variations of the speed of these movements:
 - a) High declivity = nasal flow acceleration
 - b) Minor declivity = nasal flow deceleration, very slight here

These 2 syllables (a/non) are very contrasted, according to nasality feature.

NB. On the right of the curve, the sphincter inertia does not allow the complete closing between two nasal syllables. The aerophonoscope confirms notice a physiological co-articulation of oral/ nasal syllables (contamination phenomenon), beyond a given speech rate level (beyond three syllables per second here): the base line is not reached for the pronunciation of /a/ in the case of healthy individuals.

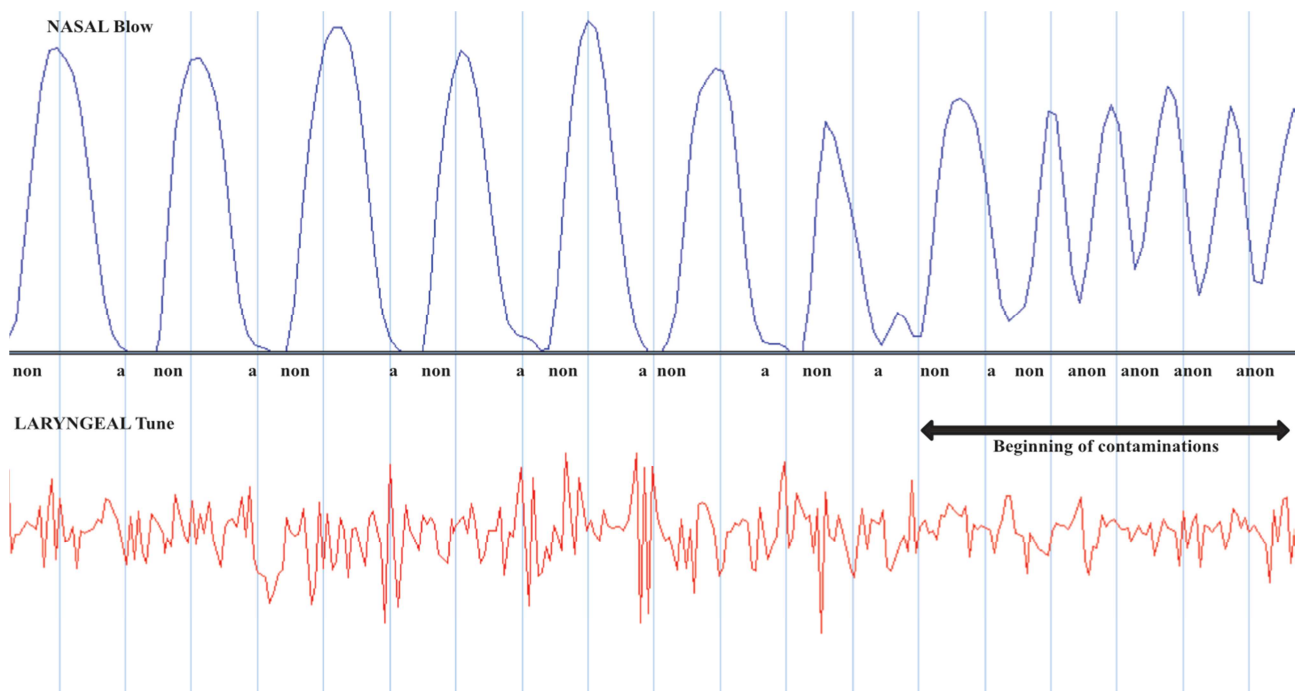


Figure 5. Closing and opening dynamic movements by a healthy person, 2 syllables/s, then 4/s.

3. A Reminder of Velopharyngeal Sphincter Physiology in Phonation

The velopharyngeal (VP) sphincter is a muscle of articulation, which plays a very important part in speaking, giving phonemes their oral or nasal character for the voice tone [1].

The phonological opposition between “oral sounds” and “nasal sounds” is achieved through velar elevation and pharyngeal muscle constriction (for oral sounds) as opposed

to velar lowering and pharyngeal muscle release (for nasal sounds), with the irregular participation of the palato-glossus [5]. The main muscle of the soft palate is the levator palatini muscle (LP) whose movements (contrary to expectations) are very fast [6], *even if there is some velar inertia* in the transitions between oral and nasal sounds. And this inertia explains different acoustic phenomena (variations of formants, phenomena of anticipation and spreading of the nasality [4]. It remains active in speaking.

In pathologic situations, velar incompetence is characterized by:

3.1. On an Aerodynamic Level

The nasal airflow is related to different factors:

- 1) Of course, to the VPS impedance, its ability to close, in other words, its role in “resistance” against nasal flow [7, 8] Warren].
- 2) This is correlated to the intra-oral pressure, and so to the buccal orifice and to the labialization or not of the oral or nasal vowels [9].
- 3) To the recoil of the tongue [10].
- 4) To the buccal orifice (Amelot [11]) for healthy individuals, there is an opposition between the oral open and closed vowels: the latter require a small buccal orifice correlated to a higher intra-oral pressure, inducing a greater oral airflow than for the open vowels. We can observe the same fact for pathological individuals with cleft malformation.
- 5) The fact that excessive “nasal loss” (NL) sometimes exists with means of compensation: narrowing of nostrils, laryngeal and pharyngeal constrictions.

3.2. On an Acoustic Level

The feature of nasality of the sounds /an/on/in/un/ is characterized by the existence of counter-formants and by changes of the frequency, intensity and bandwidth of some formants (in particular F1 and F2) in comparison with those of the oral vowels [a/o/e/œ] [9, 10]. In pathological situations, the excessive nasal resonance is called hypernasality with or without additional noises (nasal blow and ronchi). Sometimes both hypo- and hypernasality are noticed.

In 2 recent studies, the “Diadolab” software allows a precise spectral analysis, with an easy mean of vowels segmentation in the phonological chain: the counter-formants or the “counter-resonance”, have peculiar characteristics in the F1, F2, and in the zone F3-F4, above all for the opposition /è/in/ and /a/an/ (Sicard and al. [12]). In a second study, we tried to highlight the distinctive features of oral and nasal vowels in terms of the frequency variation of the formants, and their respective energy [13].

3.3. Three Important Phenomena

About velo-pharyngeal physiology must be noticed:

3.3.1. Velar Inertia

There is a slowness in transitions between nasal and oral sounds which are explained by the following fact: nasal vowels have 2 segments: the first segment has no NAF, then in the second one, the nasal air flow appears; these vowels are produced and perceived as diphthongs (Montagu, 2004; cited by A. Amelot [11], Ohala [9], [Demolin [14], Delvaux [15] Skolnick [16].

During the pronunciation of nasal sounds, there is a moment of maximum opening of the soft palate, where we have a good perception of nasality, especially for the nasal vowel /on/, which is prioritized in our assessment tests.

3.3.2. The Phenomenon of Co-articulation

For healthy individuals, most of the time, there is a co-articulation of nasal and oral phonemes: a nasal air flow for the oral vowels exists to varying degrees in every language, as Durand described [17] in 1954, then Basset [18]. In other words, a tolerable physiological margin exists for oral sounds. This small level of opening of the velopharyngeal sphincter induces a nasality in different ways for different vowels (quantified exactly at 0.4 cm³ for /i/; 1.6 cm³ for /a/) Vaissiere [19].

The feature of nasality is not reducible to the binary description (oral sound = tight sphincter, nasal sound = permeable sphincter, as defined by Chomsky (1968). The question may be asked about the minimal oral/nasal connection to modify [o] (o) to [ɔ̃] (on); [a] (a) to [ã] (an); [ɛ] (è) to [ẽ] (in).

Thus, there are different levels of activation of the LP (levator palatini) according to each phoneme. Usually, the following order is found, beginning with the phonemes which facilitate the closing of VPS (the most “resistant” to hypernasality) to the least facilitating ones (the least resistant).

For Basset [18], Vaissiere [19], nasal vowels < nasal consonants < opened vowels < closed vowels < plosives < /r/ /l/ < /s/

For Clements: Vowels < liquids < unvoiced fricatives and voiced plosives < unvoiced plosives. Starka [21] describes nearly the same.

A different order will be observed in this study in pathologic situations, mainly in dysmorphic disorders.

3.3.3. The Striking Phenomenon of Contamination

May be considered as an exaggeration of the phenomenon of nasal co-articulation, varying in audibility in different languages (for instance, French requires a high phonological opposition between oral and nasal sounds.)

This contamination may occur before the production of nasal phonemes (anticipation nasality) or after the production of nasal sounds (spreading nasality) [11]. For instance, in the French word “donc”, the first and the last phonemes are nasalized.

It also depends on different factors: speed and acceleration of speech, accents of intensity, prosody (melodic rise for interrogative and exclamatory formulations, and melodic descent for affirmative formulations.) which are important to assess.

These phonotactic facts are part of the notion of “phonetic context” House [22], Delvaux [23], Kent [24].

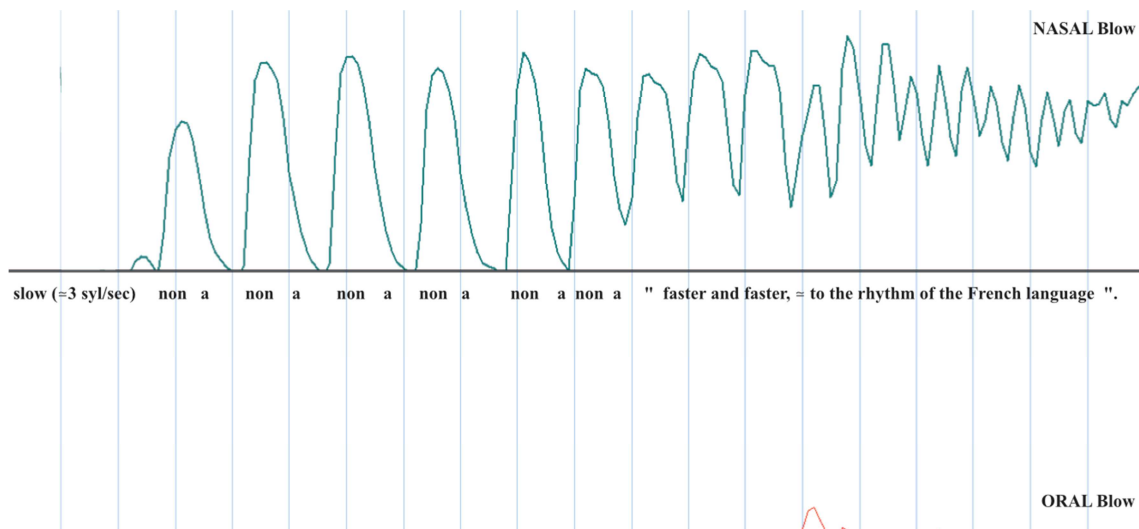


Figure 6. For instance, a physiological contamination according to rate acceleration of the sequence /a/non/.

For this healthy person, we observe the fact in the right part of the curve: the base line is not reached during the /a/ productions, beyond 3 syllables /sec.

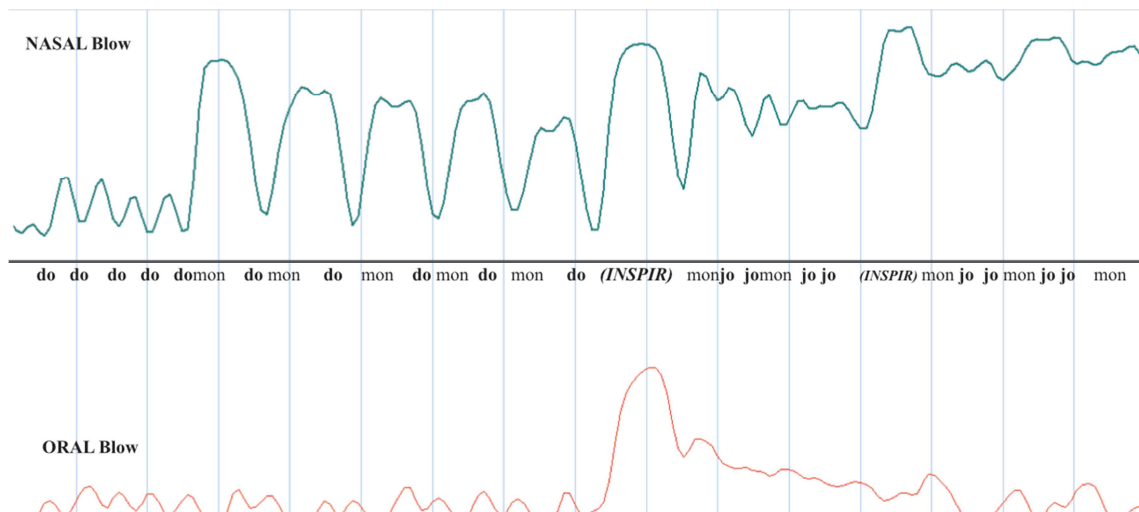


Figure 7. In this case of dysmorphy, we observe contaminations according to different syllables (/do /jo/): the curve does not reach the base line for single /do/ and then goes away in the sequence /mon/do/ and more in the following sequence /mon/jojo/.

N. B. We know the particular case of singing voice:

- 1) The singing formant is produced mostly by raising the soft palate (Levator palatini and Tensor palatini) and by the enlargement of the naso- and oropharynges (Durand) [17].
- 2) Furthermore, the high-pitched notes induce a spacing of harmonics and formants, which modify the spectrum and the perception of all oral and nasal sounds (Benguerel) [25], which are not easily recognized.

4. Aim of Our Work

Aerophonoscopic assessment, focused on the dynamic movements of the pathological VP sphincter, has been conceived in a surgical perspective for the best correction possible of the considerable nasal air flow (NAF), peculiar to the residuals of cleft palates, and all sorts of velar incompetence; and to restore the best kinetic capacities, in order to realize good

phonological opposition between nasal and oral sounds.

Surgery and rehabilitation by speech therapists have to consider all the factors of velopharyngeal incompetence.

The quality of closed/open movements of the velopharyngeal sphincter depends on many factors, which explain the variability of articulatory, aerodynamic and acoustic data. These data are not linear in healthy people nor are they in pathological ones.

These factors are ranked according to their importance:

4.1. Anatomical Factors

- 1) The degree of lack of closing, which depends on the length of the soft palate and the width of the naso-pharynges.
- 2) The flexibility of tissues (surgical after-effects, velar retraction after tonsillectomy, etc.)

The increase of nasal airflow (NAF) rate depends on the pressure gradient between oral and nasal cavities, which vary

according to each phoneme and syllable.

4.2. Dynamic Factors

The opening amplitude, the speed of closing/opening movements, the presence of phonotactic contaminations depend on several things: motor characteristics of each phoneme and syllable, melokinetic praxis capacities, stiffness, tongue recoil, means of compensation of speech disorders (for example lingual, pharyngeal, laryngeal muscle syncinesis by full contraction of the Deep Facial Muscular Chain -Delaire 75-).

4.3. Linguistic Factors

Requirements of the language and phonatory behavior, for healthy or pathological people:

4.3.1. A Nasal Co-articulation

That is to say, a tiny connection between oral and nasal cavities by a slight velo-pharyngeal incompetence, audible to varying degrees, and variable in different languages; it is very slight in French [5].

4.3.2. Proportion Nasal Oral

The proportion of nasal sounds alternating with oral sounds, which is one of the characteristics of continuous speech, of “phonological chain” (Jakobson), It exists with varying regularity and is different in every language.

4.3.3. Prosodic Variations

Strength of stress accents (of tone and of intensity), characteristic for each language - speed rate and acceleration of an individual's speech (“tempo”) induces a decrease of movement speed and so an increase of the phenomenon of contamination. (Abudoueh [25])

All these factors must be examined to assess the severity of the VP incompetence. If these tests are not made, this leads to a wrong assessment and gives “false negative” data.

4.4. Neuromuscular Factors

- 1) Flabby paralysis, organic hypotonia, myasthenia; dystonia linked or not with genetic disease;
- 2) Functional hypotonia by the absence of auditory feedback, cognitive deficiency, immaturity.
- 3) “Verbal Dyspraxia” (“childhood apraxia of speech”) and Kinesthetic Afferent Dyspraxia, involving more elaborated cognitive linguistic processes (Dewey) [28].

The 3 latter factors are assessed, in particular, with the specific called “sensitization” tests during the examination using an aerophonoscope.

5. Examination Protocol

Preliminary: in this paper, we'll use more the common alphabet notation, than the international one, such as to be easy to read, except in appendix.

5.1. Main Lines

The examination by aerophonoscope includes 3 different

tests:

- 1) Passive movement tests: with oral expiration: continuous and pulsated blow, in order to assess the soft palate scar stiffness: oral expiration increases intra-oral pressure leading to passive rise of the velum.
- 2) Active movement tests: to assess the closing capacities according to the different types of vowels and syllables.
 - a) From the more facilitating ones: open vowels [a/è/o/] associated with [p/t/k/] in words or little syntagms: “t'es pas cap”, “take up” (see examination protocol in English)
 - b) To the less facilitating ones: closed vowel associated with [v/z/j/]: “Jue view a zoo”, “jé vu zizou”.
- 3) Sensitization tests: to assess the muscular efficiency, more than pure scar stiffness
 - a) Above all, tests of *alternative up and down soft palate movements* --and pharyngeal constriction--, to assess the speed of the up and down movements and the inter-syllable contaminations between nasal syllables and oral ones, (oh /non, ah /non for instance). In French, we may use oral syllables including an [o]: this vowel which has a medium resistance against hyper nasalisation.
 - b) *Basic and action tone*: steadiness and effort exercises: scansions (staccato ho! ho! he!), crescendos, glissandos with the velar gesture of « coperto » (by mobilization of the muscular cervical chains), and slow rhythm, then at the rhythm of French, then faster and faster.

Now, we will give detail more precisely for these 3 sorts of tests.

5.2. Passive Movements Tests

They allow us to evaluate the nasal ventilation in sitting or sleeping positions.

At rest, we observe the spontaneous inspiration and expiration. This permits to detect the varying degrees of obstruction of the nasopharyngeal system and its consequences in the situation of SAS (Sleep Apneic Syndrome) and the situations of tongue protraction, with the impact on swallowing, malocclusions, cranio-facial development.

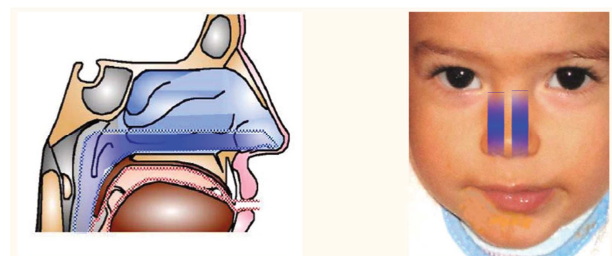


Figure 8. Normal nasal ventilation with nasal blowing.

The oral breath increases the intra-oral pressure, leading to the passive rise of the velum.

- 1) During continuous oral breath, NAF detection is in proportion to the extent of velopharyngeal incompetence,

- 2) During pulsated oral breath, a NAF detection is determined by the stiffness of the velum due to scarring, for example, or by the speed of its elevation.

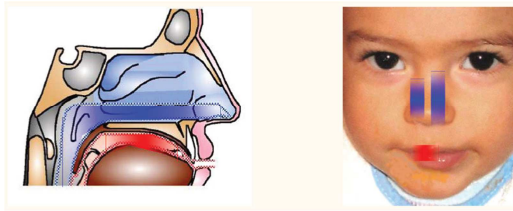


Figure 9. Continuous oral blow, with nasal loss.

5.3. Active Movements Tests

During the tests of production of oral/ nasal sounds, according to our protocol, we shall indicate for convenience the “nasal syllables” - the syllables *containing at least one final nasal vowel*, a satisfactory condition to show contaminations; with the preference for the nasal vowel [ɔ̃] (on): in French which gives greater perception of nasality

than the nasal vowels [ɑ̃], [ɛ̃], [œ̃] (an/ in/un/ in French)[14].

It assesses the severity of nasal air losses by the pronunciation of all isolated closed vowels [i], [y], [u]; (/i/u/ou/ in French) and open ones ([a], [ɛ], [ɔ]; (/a/è/o/ in French) and associated with the oral, unvoiced and voiced consonants. Each oral consonant is tested with an open and then a closed vowel ([pataka] then [pitiki], for example; [va/za/ja/] and [vi/zi/ji]). They are tested in amusing sentences for little children.

First of all, it shows the abilities of complete closing of the velopharyngeal sphincter for a large spectrum of phonemes with increasing levels of difficulty:

- 1) From the easiest open vowels: [a/è/o], to the difficult closed ones: [i/u/ou].
- 2) From the easiest syllables (pataka), to less easy ones (viziji).

In pathological cases, the more the amplitude of closing/opening decreases, the greater the nasal air flow is.

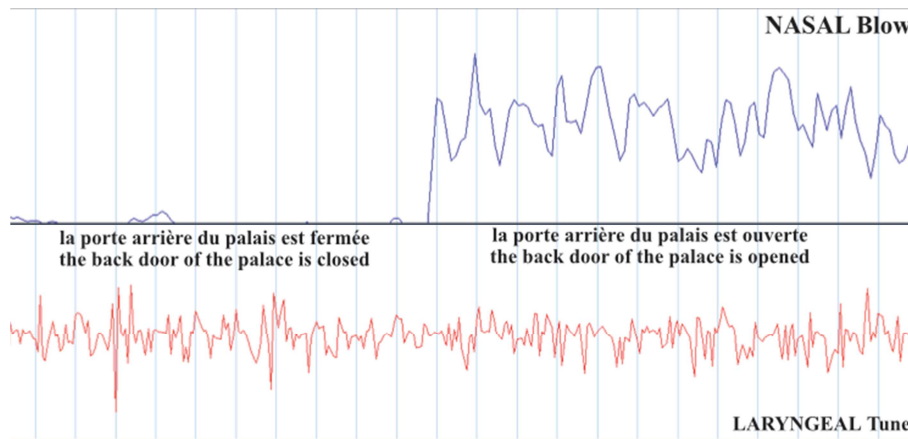


Figure 10. No nasal loss and excess of nasal air flow.

In this diagram, (upper line) during twelve seconds, we observe:

- 1) the absence of nasal air flow by the absence of a curve
- 2) the excess of nasal flow: it appears in peaks, related to each syllable

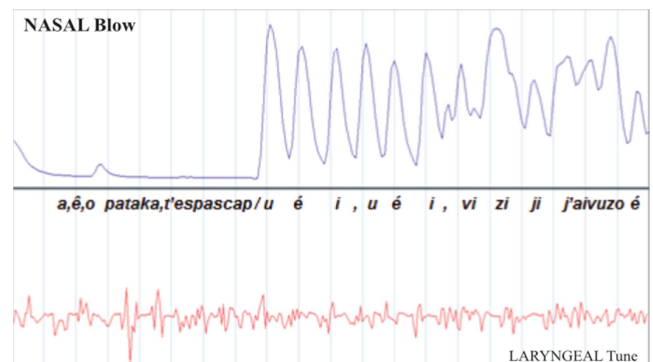
More specifically, we have to examine this phonemes list:

- 1) From easy, facilitating vowels and consonants ([a /è /o], and unvoiced plosives [p/t/k] (/pataka/ potoko/), within some amusing words or phrases such as “toi t’es cap”, “take up”, etc.
- 2) to less easy vowels and consonants ([i/u/]) and voiced consonants [b/d/g/]; [v/z/j/], related to closed vowels (/bidigi/ viziji/) within words or phrases (like “dog bed”, “bigoudi”, “Jue views a zoo”, “j’é vu zizou”)
- 3) And the intermediate phonemes inside syllables («show/ a fa/ce/» “(elle)/se /fa/cha/, “des/ba/gues/”).

NB: the liquids /l/r/ and the half consonant /ll/ (within « /l’o/re/ille” », “a /low/ row/”) haven’t usually any range of severity. This fact opens up research perspectives.

So, we objectified different phenomena of dissociations:

- 1) Dissociation between the syllables with closed vowels [i/ou/u] and the syllables with the open vowels [a /è/o].
- 2) Dissociation between voiced and unvoiced consonants ([p/t/k/] and [b/d/g/], for example).



No nasal Loss (open vowels) / Nasal Loss (closed vowels).

Figure 11. A case of dissociation between some vowels and some consonants, inside syllables.

On this diagram we observe the *dissociation* between the vowels and the consonants:

1) on the one hand, the nearly closing for open vowels /a/, /è/, /o/ and on the other hand, the opening for the vowels /u/, é/, i/;

2) On the other hand nearly closing for the syllables /pa/ta/ka/, but opening one for the syllables /vi/zi/ji.

Karling and al. [30] already observed these 2 dissociations.

Further more, we notice a dissociation between plosive and fricative consonants ([p/t/k] and [f/s/ch/], for example).

These tests provide a mean of comparative assessment, based on reproducible tests before and after treatment.

5.4. Sensitization Tests

Show the true severity of velar *incompetence within continuous speech*, according to the specificity of the language and the prosody (accents, intonations and rhythm of speech, in particular).

The tests allow to reveal one or several neurological components. Indeed, their purpose is to objectify the mechanisms of the VP sphincter muscles:

- 1) their steadiness by the study of basic tonus with a continuous sound:
- 2) their tonus of action, which can be weakened in the tests of effort (with hypertonic movements)
- 3) These tests also assess the stiffness of musculo-aponevrotic structures.
- 4) Their speed of action and flexibility, by the test of accelerated pace, during the succession of nasal/oral syllables.

Thus, their muscular potential and not only the level of nasal air loss.

5.4.1. Steadiness (Figure 12) or Unsteadiness (Figure 13)

Of velopharyngeal muscles (basic tonus) by the test of holding on a nasal vowel /on/, or a distorted vowel (/i/, /u /).

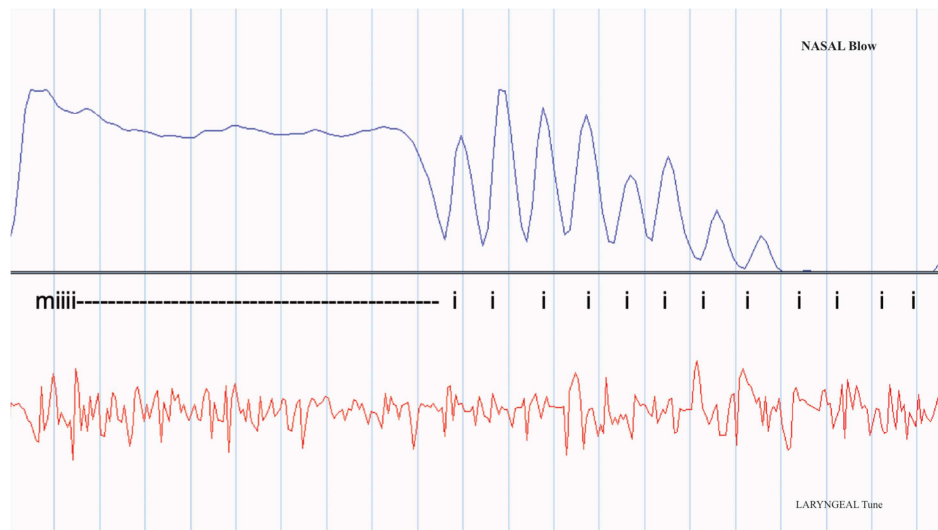


Figure 12. A case of velar steady tone.

On this diagram we objectify: - a steady line by holding on /i/ with constant loss, then the improvement by means of “staccato” (repeated and stronger /i/).

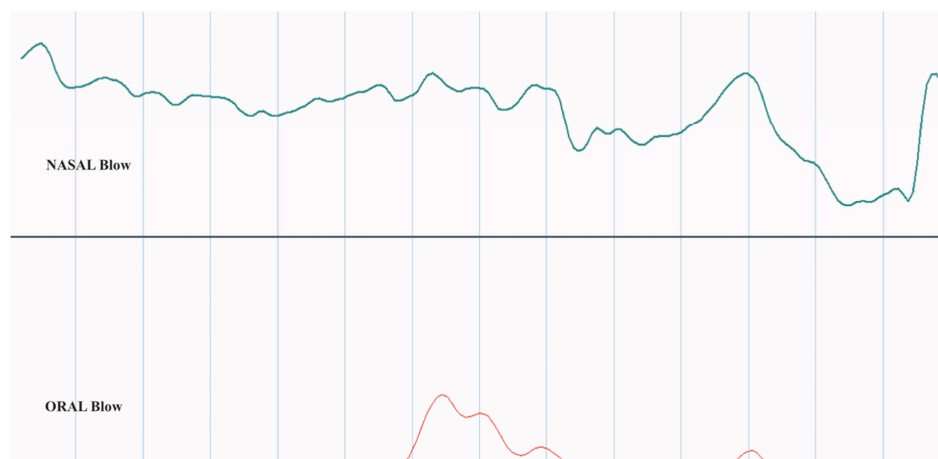


Figure 13. Here, the basic tone is unsteady when holding on the vowel /i/.

The poor steadiness of their base or action tonus evokes a neurological disorder such a dystonia or coordination or praxis disorders

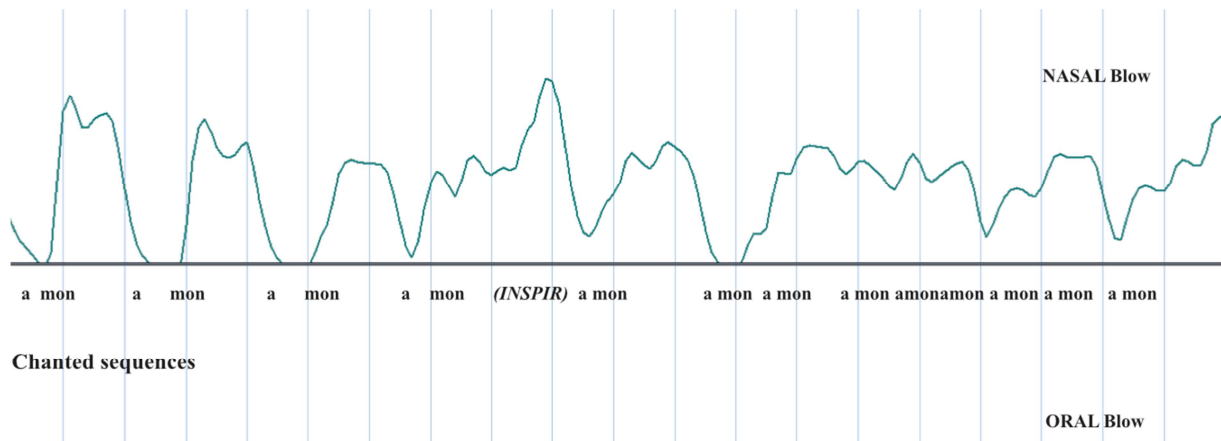


Figure 14. In this case of "Verbal dyspraxia" ("childhood apraxia of speech").

We notice that the first three sequences "a/mon" are regular, but the following ones are inconstant slowly and speeding up.

5.4.2. Their Tonus of Action

Which is assessed with the effort tests:

- 1) Accents of intensity: we ask them to make the staccato /hi / /hi //hi / hu /hu/ hu (Figure 12 and 15)
- 2) Pitch accents: we ask them to do a glissando towards

high-pitched sounds.

We may notice 3 situations:

- 1) If there is improvement or normalization: it suggests a functional incompetence
- 2) If there is no improvement: it would indicate either isolated or additional neurological disorder (hypotonia), or scar stiffness
- 3) If continuous closing: it is a case of hypertonia.

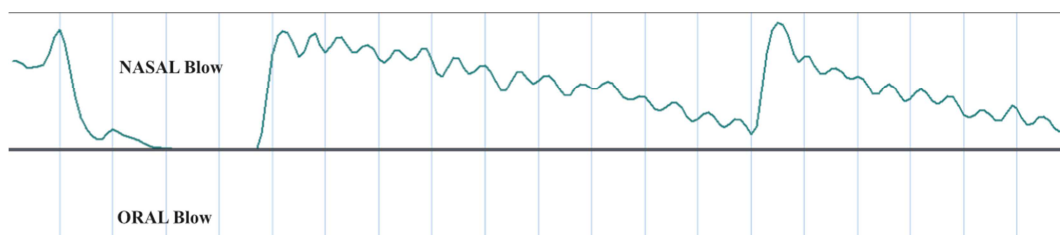


Figure 15. Here we can observe an effort test with energetic repetition of the phoneme /u/ and /i/, stronger and stronger (after 2 inspirations).

5.4.3. Their Speed of Up and Down Alternative Movements

Of the VP sphincter, with the test of successive sequences of Nasal Syllables / Oral syllables (NS/OS) testing its melo-kinetic praxis, once or twice a second, then in the rhythm of the French language, then more rapidly, if possible.

The phonemes are called "facilitating" phonemes because they favor the active and passive movements of the rise of the velum and the closing of the velopharyngeal sphincter.

The oral syllables contain all the oral consonants of spoken French; they are repeated so as to make vowels almost mute. We must observe:

- 1) The different degrees of amplitude of the curve, in proportion with the airflow and the width of the nasal port.
- 2) The speed of these opening/closing movements is assessed by the degree of declivity of the curves. We may observe a slowness of the curve, which indicates a slowness of the VPS closing (see Figure 17).
- 3) The presence of contaminations (by prolongation of

velopharyngeal incontinence) of nasal syllables, containing at least one final nasal vowel, on the following oral syllables, in the following sequences:

a) From the most contrasting:

for the alternation of oral and nasal vowels /a/an/; /a/on/; /o/on/.

For the alternation of Nasal syllables NS / Oral Syllables OS, within French locutions:

"Mon/papa; ta-ta-/lon; caca/mion; sa-sa/von; cho-cho/mons; fai-fai/sons; vo-vo/yons", for young children; "mon/coco, mon/babar, mon/bobo, mon /dodo, mon/gars-gars, mon /foufou,... or within English ones: « time-time, mankind-mankind, same-same, shame-shame and so on".

b) To the less contrasting ones, for the alternation of NS/OS containing more difficult vowels (closed ones /i/u/ou): within French words "pi/ment, ti/lons, qui/gnon; bu/vons, di/nons, gui/don; fi/lons, si/mon, chi/gnon; vi/son, ju/ment; ri/ons, or within English ones: «indeed-indeed, been-been, viewing-viewing, on him-on him».

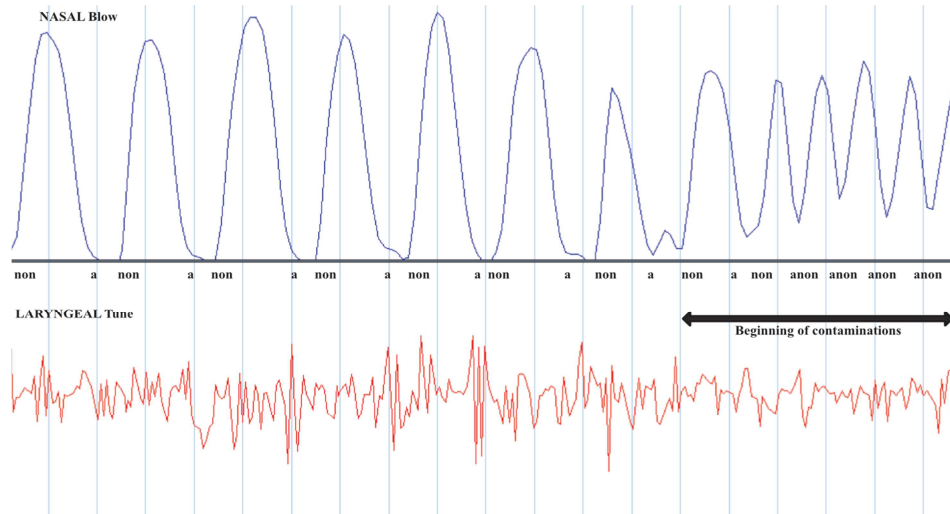


Figure 16. Physiological contamination during contrasting sequences of Nasal Syllables/Oral syllables, (NS/OS), faster and faster, up to 4 syllables per second, in a healthy subject.

On these curves showing the melokinetic praxis in the alternation of Nasal syllables/ Oral syllables, we can observe:

On the right of the curve, we can see the phenomenon of contamination during the acceleration of air flow, which is a *physiological contamination* of oral syllables on the nasal syllables beyond a certain speech rate (beyond three syllables a second here): the base line is not reached for the pronunciation of /a/.

The sphincter inertia does not allow the whole closing of

an oral syllable between two nasal syllables. The aerophonoscope confirms *the inhomogeneous character of nasal flow* within one-third of a second in the usual conditions of speaking (for a healthy subject).

The whole curve of *deflection remains rapid*, proving a good action tone; contrary to the following case, (figure 17) where we observe the slowness of rise of the velum during the pronunciation of /a/.

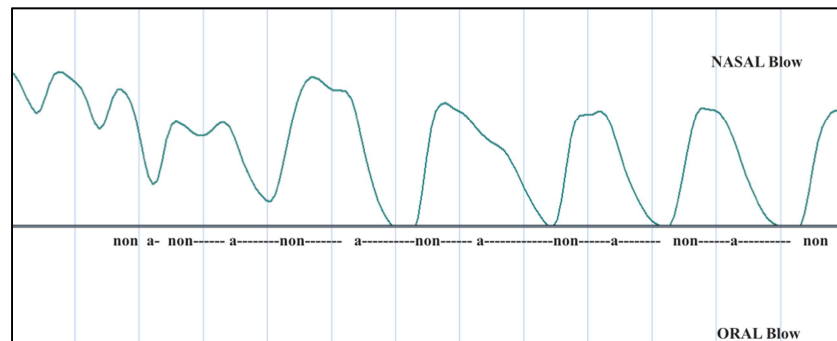


Figure 17. Slow velar rise, when pronouncing /a/ (in the sequence /a/non/a/non/).

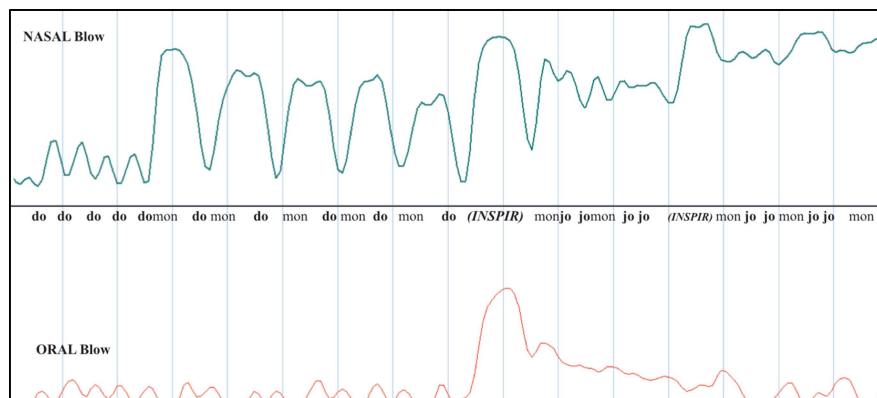


Figure 18. A case of dysmorphic disorder: the curve does not reach the base line for the syllable /do/, isolated or in the sequence /mon /do/: its curve is nearly at the same distance (no contaminations), and then is making away in the sequence /mon/jo/jo/ (contaminations).

These sequences involve more nasality for these oral syllables.

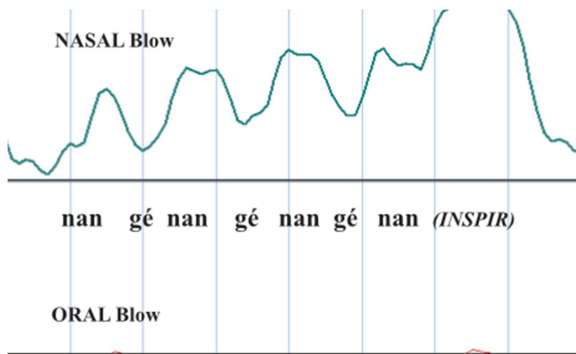


Figure 19. In this case of neurological disorders (hypotonia), we notice an increase of contamination from /nan/ to /gé/.

5.5. Three Levels of Severity for Velopharyngeal Incompetence

5.5.1. Minor Severity

- 1) No Nasal loss for oral blow
- 2) Light nasal loss for articulation
- 3) Improvement with accents
- 4) Normal speed, no contaminations

5.5.2. Medium Severity

- 1) Nasal Loss with pulsated oral breath
- 2) Moderate nasal loss + in articulation
- 3) Slight improvement with accents,
- 4) Normal speed and moderate contaminations+

5.5.3. High Severity

- 1) Nasal Loss with continuous and pulsated oral breathe
- 2) Significant nasal loss++ for articulation
- 3) No improvement with articulation efforts
- 4) Light slowness of velar rising and frequent contaminations ++

6. Results

6.1. Cohort of 652 Individuals

- 1) Children: 605 between 3, 5 and 19 years old; Mean age = 8, 3years old
- 2) Adults: 47 between 20 and 84 years old; Mean age = 44 years old

We examined 3 sorts of pathologies, related or not to a genetic etiology:

6.1.1. Pure Dysmorphic Disorders: 348

- 1) Major ones before or after the primary surgery, regardless of the type of cleft (bilateral or unilateral bony

palate cleft, soft palate cleft);

- a) Bilateral cleft: 33
- b) Unilateral cleft: 110
- c) Soft palate cleft: 79

2) Minor ones have a velopharyngeal disproportion with a short velum and/or large pharyngeal cavity ("Pricva" syndrome); with or without posterior medial slot, with or without split uvula or submucous cleft; sometimes revealed by tonsillectomy and adenoidectomy: 126

6.1.2. Pure Neurological Disorders: 84

- 1) Major ones: 38 Flaccid deficit, spastic or flaccid-spasmodic deficit
- 2) Minor ones: 39 Hypotonia and dyspraxia, with or without soft neurological syndromes.

Among them: 12 "Verbal Dyspraxia", called "childhood apraxia of speech" (because of bad programming of phonetic sequences, and linguistic ones. (Dewey [28], Forrest [29])

- 3) Specific dystonia: 7

6.1.3. Pure Dysfunctional Disorders: 27

Called "mislearning" disorders, because these individuals have a good potential.

- 1) because of "wanting troubles": psychological immaturity, antalgic attitude (post tonsillectomy)
- 2) because of "knowing troubles": deafness, mental retardation, culture or parental mimic

6.1.4. Mixed Types: 193

Mainly by the association of a dysmorphic disorder and a neurological one,

- 1) Bilateral and unilateral cleft palate: 38
- 2) Cleft soft palates: 84 A part of them including these genetic syndromes: Pierre Robin sequences (11); 22q11 syndromes (41) syndromes (Touraine, Stickler, Cornelia de Lange, Prader-Willi, Angelman, Ellis von Creveld, Van der woude, Francheschetti-Klein, oro-palato-digital Klippeil- Feil, Neuro-fibromatosis 1, Baraster-Winkel syndromes

- 3) Velo-pharyngeal disproportion ("Pricva" syndrome): 71

Among all these mixed types, we found also 46 individuals with the peculiar neurological component of "Verbal dyspraxia" (in French) or "Child apraxia of speech" (in English)

6.2. An Aerodynamic Typology

Using an aerophonoscope we objectified the three dynamic types of velopharyngeal sphincter kinetic disorders, correlated with three etiologic frames:

Each pure disorder is characterized by the following criteria:

Cohort of 652 individuals

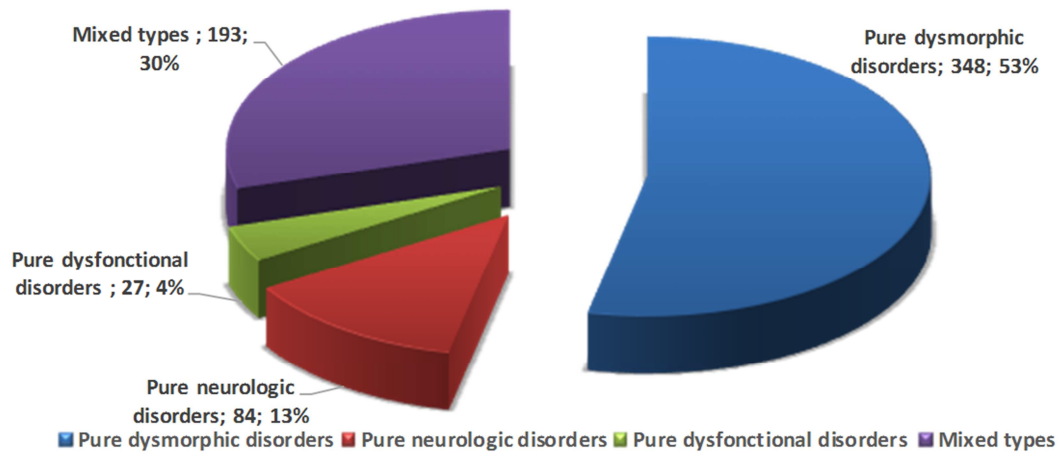


Figure 20. Cohort of 652 individuals.

Table 1. The 3 types of velo-pharyngeal dynamic function.

	Passive movements with buccal flow	Active movements articulation of oral syllables	Basic tonus holding on a nasal vowel	Effort test hypertonic movements	Sequences nasal / oral syllables, a/non, a/bon
1 Dysmorphic disorders 348 individuals	Various nasal loss according to rigidity and the size of the gap	Either Great nasal loss 26% Or 2 sorts of Dissociations: a-Dissociation 44% between open vowels [a] [o] [ɛ] less distorted than closed vowels [i] [u] [y] b Dissociation 30% between unvoiced plosives [p][t][k] less distorted than voiced consonants [b][d][g]	Steady nasal loss 95 %	Nasal loss improvement 63 % according to the size of the gap and the rigidity	-most often decrease of closing/opening movement amplitude -Contaminations according to the severity
2 Dysfunctional disorders 27 individuals	NAD	Dissociation 66 % between - Plosive consonant [p/t/k] more tonic than - Fricative consonants	Steady nasal loss 100 %	Nasal loss improvement 100 %	Fluctuating amplitude according to attention
3 Neurological disorders 84 individuals		Different nasal loss observed according to etiology see table 3	Often unsteady 76 % in event of dystonia or dyspraxia	Small improvement in event of hypotonia	Slowness (closing or opening delay) 53 % in event of hypo or hypertonia; +/-increase of Contaminations
4 Mixed disorders 193 individuals		all kinds of up disorders	Unsteady 42 %		

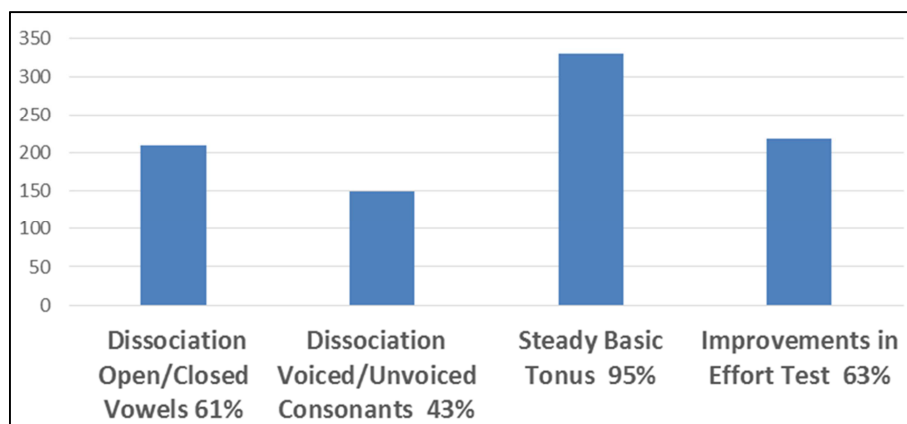


Figure 21. Dynamic function characteristics in dysmorphic disorders of 348 individuals.

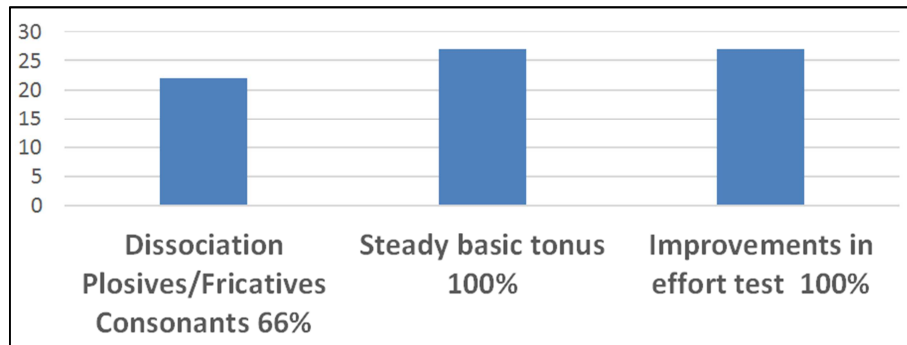


Figure 22. Dynamic function characteristics in dysfunctional disorders of 27 individuals.

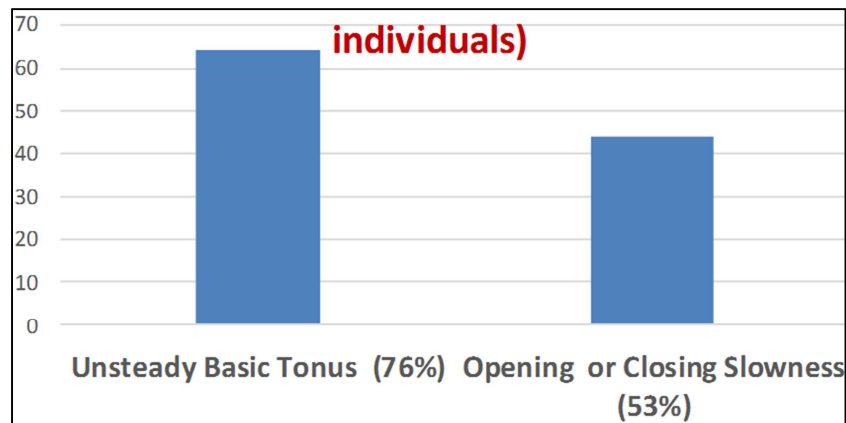


Figure 23. Dynamic function characteristics in neurological disorders of 84 individuals.

6.3. Comments

- 1) If there are significant contaminations, in less contrasting alternation of Nasal Syllables /Oral Syllables, it may suggest structural disorders or fairly intense neurological disorder: surgical solution of filling, softening or with muscular reconstruction of the sphincter).
- 2) If there are moderate contaminations, it often suggests a functional incompetence: solution by means of speech therapy for 4 months and monitoring of the outcome.
- 3) If there are fluctuating contaminations, it may indicate neurological disorders: dyspraxia, dystonia +/- hypermetria.

The neurological components fall within genetic syndromes, combining a dysmorphic component with a neurological one (often with a +/- pejorative prognosis). This neurological component requires specific reconstructive types of surgery (for instance: sphincteroplasty, pharyngoplasty, muscular transposition, etc. according to the action tonus).

Many children have these mixed types including different correlated disorders:

- 1) Either by co-morbidity, within genetic syndromes which add dysmorphic damage to neurological disorders++ (“soft neurological syndrome with dyspraxic disorder, hypotonia) and/or deafness of perception,
- 2) Or by associated factors, which are linked to etiology: velar stiffness by a hypertrophic process (adenoids or tonsils) added to a deafness of transmission; buccal

ventilation, swallowing disorders, dental malocclusion, psychological immaturity and dyspraxia disorders.

These factors may each evolve independently of each other during the child’s development, causing rehabilitation to be more difficult than was initially estimated, and giving the *velum variable dynamic possibilities*.

Velopharyngeal dysfunction is related to ventilation, Eustachian tube, swallowing and occlusion dysfunctions, as well as maxillofacial development, which increase the severity or the slowness of the rehabilitation. A velopharyngeal disorder requires all these functions to be tested.

During the child’s development, one functional abnormality may involve one or several structural pathologies, just as one structural pathology may lead to one or several functional disorders.

We can find, for example:

- 1) Most often, dyslalia (articulation disorders): naso-velar air loss leads to the decrease of intra-oral pressure, which gives a lesser gradient of pressure for labial ([p/b]), dento-labial ([f/v]) and dento-lingual ([s/z/t/d]) sphincters,
- 2) Velopharyngeal dysmorphia may induce a tubal dysfunction with recurrent otitis, which itself maintains articulation disorders,
- 3) Nasal hypoventilation, inducing lingual protrusion and malocclusion [1],
- 4) Primary or mixed swallowing, involving upper maxillary dysmorphia, which itself maintains

articulatory disorders [1

5) An excessive NAF may induce laryngeal constrictions

and thus dysphonia.

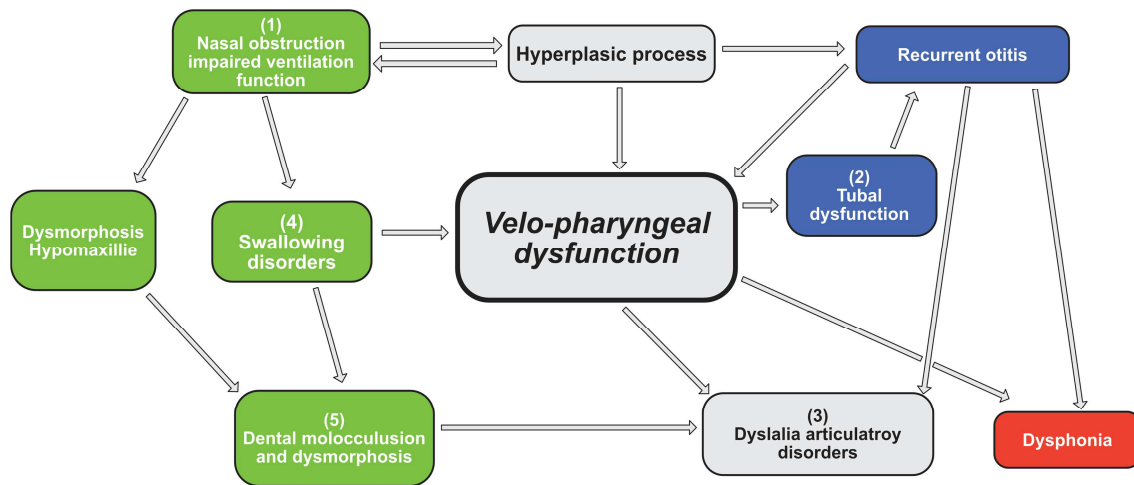


Figure. 24. Etiopathogenic links between velo-bucco-facial disorders.

Ventilation, tubal, swallowing, occlusion dysfunctions are correlated to velar function and lead to articulation +/- vocal severe disorders. They involve multidisciplinary care and different sorts of speech-therapy.

These correlated pathologies develop in connection with the others, inducing improvements or worsening, sometimes beyond surgery or rehabilitative treatments of the cleft palate.

So, speech therapy may be an illusion, because of the importance of one factor or another, and on the contrary, it may improve one or several factors at some points of development.

For example, some factors (hearing or psychological ones) will disappear around the age of 2-4 years old, or later up to 6 years, on an average, under the influence of their own medical, surgical or rehabilitation treatments. And it "purifies" the dynamic aerophonoscopic type. Their evolution is

difficult to realize, and so the surgical choice is delicate.

6.4. Concerning the Neurological Disorders

They may present some combinations of syndromes:

- 1) For instance dyspraxia + dystonia syndromes;
- 2) Flaccid deficit + ataxic dystonia,
- 3) Dyspraxia + hypotonia.

Differential diagnosis of neurological disorders: This table 3 is linked with the dynamic criteria of dysarthria and dysphonia, described by Darley and Aronson [27].

Table 2. Differential diagnosis of velo-pharyngeal neurological disorders.

	Opening / Closing Dynamic movements	Basic tonus [on]	Programming of nasal/oral syllables sequences
A - Dyspraxia and apraxia 12 individuals	Various aperta rhinolalia	Unsteady by motor impersistence	Fluctuating because of A-V dissociation 1) sometimes correct (when Voluntary) 2) sometimes incorrect (carry-over contaminations when Automatic)
B1 - Flabby deficit 18 individuals and Hypotonia 27 individuals Pseudo-Bulbar and Bulbar Sd. or Deuto-neurone defici (unilat)	Aperta rhinolalia ++ but improvement with effort	Steady	1) Nasalisation because of hypotonia (contamination of the OS. by the NS.) 2) or late closing (slowness of contraction)
B2 -Spastic deficit 20 individuals Of the Proto-neurone (supra bulb) (ministroke, degenerative impairment)	Clausa rhinolalia ++	Steady	1) Oralisation by hypertonia (contamination of the NS by the OS) 2) or delay in opening (slow relaxing)
C - Dystonia 7 individuals C1 – extrapyramidal 3 individuals C2 – ataxic (4 individuals) including 2 syndrome 22q11	Nearly Clausa rhinolalia by hypokinesia Fluctuating 1) slowed by dyschronometria 2) exaggerated by dysmetria	Steady Unsteady + Tremor	Oralisation (Contamination of the NS. by the OS.) Fluctuating: either oralisation or nasalisation

Among mixed types, and pure neurological disorders, we may notice the very original phonetic and phonological criteria of “Verbal Dyspraxia” or “Childhood apraxia of speech”, which are infrequent. They are caused by a bad programming of phonetic sequences. (Dewey [28], Forrest [29].

In this population of 46 children (mean age = 6,2 years old) who present this “verbal dyspraxia”, with dysmorphic disorders (34) or pure neurological disorders (12), we found these different peculiar characteristics:

- 1) *Random substitutions* of one vowel for another, and/or substitutions of a consonant for another as well = 100% + and thus, amongst them, random and fluctuating *inter-syllable contaminations* between nasal vowels and oral ones = 54%. These random substitutions lead to very quick sequences of rhinolalia, sometimes open, sometimes closed, sometimes absent.
 - 2) Vowel *imprecisions +/- blurred* consonants = 78 % + and thus, among them, oral vowels with a *fluctuating* and small nasal loss.
 - 3) *Reduction* of syllable sequences in words over 2 or 3 syllables. That involves an increase of nasality contaminations within these words = 43 %
 - 4) *Dissociation between a bad automatic expression and a good effort one*: 63 % (contrary to apraxias)
 - 5) An *unsteady* basic tonus = 54 %
 - 6) *Slowness* of the rise of the velum = 32%
- (see another study of 9 individuals (Rousteau [32])

7. Contributions of the Aerophonoscope for Therapeutic Decisions

This classification by aerodynamic types is original and contributes to guide the secondary surgery and also to justify the interest or not of speech therapy. It shows the velopharyngeal movements, whatever the residual gap: their amplitude, their speed, (correlated to softness or tonicity), their steadiness and flexibility.

It is important, before making any therapeutic, surgical and rehabilitation decisions, to assess the severity and type of VP incompetence. With the following criteria:

- 1) The overall quality of intelligibility *at the rhythm of the language* [5]
- 2) The aerodynamic velopharyngeal type, assessed by the tests of active and passive movements and sensitization *more* than the extend of nasal airflow.

The surgical correction of these parameters is enabled by the range of different surgeries [34] Naiman, the choice for a given type and by the surgical calendar developed in our Cleft Palate Center [37, 38, 39, 40] Talmant.

Altogether, we have to discuss the following decisions for secondary surgery:

7.1. If It Is a Purely Functional Disorder

Only indication of speech therapy, +/- ENT and psychological care, then a reassessment of Nasal Losses (especially the

amplitude of closing/opening, and the effort tests).

7.2. If It Is a Purely Dysmorphic Disorder

1) with a gap: lengthening surgery (by plasty, and/or muscular transfer (Sommerlad, Intravelar veloplasty [35]; Andrades [36], R Mann [43]; and/or lipofilling, speech therapy; then a reassessment of residual Nasal Losses (especially by effort tests)

2) With stiffness: softening surgery: muscular transfer and Z or Y plasty, with intense speech therapy, then a reassessment of range of movement (especially with tests of passive movements and of sensitization in the sequences of oral and nasal sounds at the rhythm of the language).

7.3. If It Is a Purely Neurological Disorder

1) With hypotonia often associated with dyspraxia: muscle transfer surgery, speech therapy, then a reassessment (by the tests of effort, of sensitization)

2) With flaccid deficiency: reconstructive surgery by Orticochea sphincteroplasty or pharyngeal flap these two sorts of surgery may involve a Sleep Apneic Syndrome (SAS), sooner or later, and the sphincteroplasty may be reduced according to evolution and rehabilitation.

Then speech therapy and a reassessment of nasal loss and residual tonus.

7.4. If It Is a Mixed Type

With two or three components, the choice is more difficult:

1) Dysmorphic moderate type with a predominant functional component: supervision after etiological treatment or speech therapy (ENT, psychological care), then reassessment of nasal losses by assessment of the amplitude of closing/opening, and effort tests then § 2;

2) Dysmorphic moderate type with a predominant neurological component: (syndromic, e.g. 22q11): surgeries of §3;

3) Severe dysmorphic type with neurological or dysfunctional component: surgeries of §2.

7.5. From a Rehabilitation Point of View

The aerophonoscope provides a fun and efficient means of rehabilitation, it enables a visual feed-back of nasal flow, oral flow, laryngeal vibrations, and makes the rehabilitation of all these movements amusing, in particular the velar movements, the rehabilitation of which *is considered to be difficult*.

It significantly facilitates the control of:

- 1) Movements of velar closing/opening (nasal sounds versus oral sounds);
- 2) Start-up control of vocal vibrations (voiced consonants versus unvoiced ones) and indirectly the kinesthetic sensations of the glottic sphincter in synergy with that of the velopharyngeal sphincter, we call the glotto-velar synergy.
- 3) The mixing of these two neuromuscular controls.

8. A Classification of the Vowels and Syllables

In pathological situations, we could classify them according to their facilitating power to close the VPS (or their “resistance” against hyper-nasality).

Using the aerophonoscope, we recorded different dissociations, according to their voicing, opening features; plosive or fricative modality, and we noticed:

8.1. Concerning the Vowels

Open vowels are more facilitating than the closed ones.

8.2. Concerning the Consonants

- 1) The unvoiced plosives /p/t/k/ are more facilitating than the voiced ones /b/d/g/. Therefore, the syllables /pataka/ are more facilitating than /pitiki/ and /badaga/
- 2) The unvoiced fricatives /f/s/ch/ are more facilitating than the voiced ones (/v/z/j/)
Thus: *the voicing feature influences the nasality feature*
- 3) The liquid /l/r/ and the /ill (= [j]), do not have any rules.

Table 3. Several types of phonemes dissociation s in cases of dysmorphic disorders. Via functional exploration with aerophonoscopy.

Several dissociations between French phonemes, from the best facilitating closure = the best “resistant to nasalisation” to those which don’t facilitate closure		
1) Open Vowels which facilitate closing more than closed vowels	[a] [e] [ɔ] [i] [u] [y]	For instance, Open vowel [a] < Closed vowel [i]
2) Consonants		
Unvoiced plosives more facilitating than	[p] [t] [k]	therefore
Voiced plosives	[b] [d] [g]	pa ta ka < bi di gi
Unvoiced fricatives more facilitating than	[f] [s] [ʃ]	therefore
Voiced fricatives	[v] [z] [ʒ]	fa sa ʃa < vi zi ʒi
Liquids [l] [r] and semi consonant [j] on their own	[l] [r] [j]	la ra ja < li ri ji

Altogether, we may rank this order from more facilitating phonemes to the less facilitating ones:

Open vowels < unvoiced plosives < unvoiced fricatives < voiced plosives < voiced fricatives < closed vowels < nasal consonants < nasal vowels.

These data more or less explain the lack of correlation between anatomic and aerodynamic data:

The aerophonoscope examinations prove the variability of the nasal air flow – nearly within a third of a second - according to each phoneme or syllable type; and the phonotactic links between nasal and oral sounds.

9. Discussion and Working Hypothesis

9.1. Assessments for Therapeutic Solution

The aerophonoscopic assessment of the pathologic velopharyngeal sphincter movements is conceived, above all, to choose the best surgical solution and the best ways of rehabilitation, in order to correct:

- 1) The excessive nasal air flow because of the lack of complete closing
- 2) Its kinetic behaviour and its muscular potential: their incorrect muscle orientation, and so their lack of tone, their stiffness, their speed and their steadiness.

Thus, we focused especially on:

- 1) *Aerodynamic data of nasal air flow for oral sounds* and not on the proportion (ratio) between nasal and oral airflows, (called “nasalance” in nasometry). The latter don’t allow to analyse the characteristics of Nasal Loss in the “phonological chain” of speech.
- 2) *Assessment of contaminations of the nasality feature* especially on the oral sounds among nasal sounds in the phonological chain. In the French language, continuous speech is characterized by frequent alternations between

oral and nasal sounds.

These contaminations conduce mainly to the severity of the pathology.

Furthermore, we didn’t choose all the phonemes, to shorten these drills for children and so to analyse the impact of articulation main features (voicing, plosive, fricative features) on the nasality one, besides the rythmo-melodic facts.

9.2. Velopharyngeal Incompetence: An Acoustic or Aerodynamic Disorder

According to Amelot [11] we know, for healthy individuals, that aerodynamic data (air flow speed and pressure) for the vowels are more correlated with the acoustic signal (78% of cases), than with the anatomic or articulatory data (42 % of cases), in particular because of velar inertia. Feng (2004), cited by Amelot, and Cohn [42] demonstrated that the importance of nasality is not linked with the nasal airflow extent.

9.2.1. From an Acoustic Point of View

Open rhinolalias are caused by the participation of a nasal resonance cavity beyond a tolerable physiological margin of nasality, for each oral vowel and each oral syllable according to:

- 1) The amplitude movement and the defect of closing
- 2) The slowness of closing
- 3) The acceleration of the speech rate, which depends on our “melokinetic praxia” (Luria)

9.2.2. From an Aerodynamic Point of View

The excessive opening induces an abnormal flow (cm³/sec) which is correlated to:

- 1) The diameter width of the opening of the velopharyngeal sphincter (cm²).
- 2) The air speed which is linked with the strength and pressure inside the mouth (Newton/Pascal) and so the sphincter resistance according to individual oral sounds,

which facilitate sphincter closing to varying degrees. That is why these oral sounds are called more or less “resistant” to hyper nasality or “facilitating phonemes” for VPS closure.

Moreover, according to the hypothesis of A. Amelot [11], *the acoustic spectrum of the nasal vowels, in healthy individuals, is modified when there is an airflow variation*, i.e. the closing/opening speed variations lead to the phonological oppositions between nasal and oral vowels.

Indeed, the nasal airflow fluctuates continuously: the more the diameter decreases, during the VPS closing or opening, the more the air speed increases.

Beyond Bernoulli’s law, the more significant assessment is the following: to show acceleration/deceleration during these dynamic movements. Now, the aerophonoscopic sensors have rightly thermistors which detect the lesser airflow variations, caused by such dynamic movements.

In others words, the severity of a velopharyngeal incompetence is highly measured by the speed variations of these closing/opening movements, during the alternation between nasal and oral syllables, when the latter include the less facilitating syllables (/bi/di/gi/; /vi/zi/ji/).

Thus, acceleration depends here on 3 differentials:

- 1) air flow (dV)
- 2) section (diameter width) (dA)
- 3) speed (du)

The latter depend on x (meter) and t (sec).

The flow is:

$$V(m^3/s) = A(m^2) \cdot u (m/s)$$

Acceleration is the derivative of the flow:

$$d(V) = d(A \cdot u)$$

then

$$d(V) = \frac{\delta(A \cdot u)}{\delta A} \cdot dA + \frac{\delta(A \cdot u)}{\delta u} \cdot du$$

so

$$d(V) = u \cdot dA + A \cdot du$$

as

$$du = d(x/t) = dx/t - x/t^2 \cdot dt$$

we have

$$d(V) = u \cdot dA + A \cdot (dx/t - x/t^2 \cdot dt)$$

These facts are near to the Venturi effect; we could say that when the section is decreasing, the air speed is accelerating, and his time is shortening.

9.3. The Phenomenon of Contamination

It betrays also the severity. It results from the “phonological context” (Kent and Winifie [24]). It is easy to detect by means of the called “sensitization” tests. It depends on:

- 1) The speed of succession of nasal and oral sounds (“mon/day”, “man/kind”, “prête ton peigne à Clément”, “a/non”, “mon/papa; “mon/dada”, etc.) and it increases in a very significant way, with the slightest acceleration of the speech rate,
- 2) The proportion of nasal sounds compared to oral ones, in the words or in the sentences,
- 3) The predominance of facilitating or non-facilitating oral phonemes in the phonological chain,
- 4) The prosodic variations and inherent accents of the language

But we have to pay attention to the fact that there is a tolerable physiological margin of nasal air loss, assessed especially for some vowels and syllables, those we described in pathology as less “facilitating”: closed vowels ([i], [u], [y] and the syllables /bi/di/gi/ and /vi/zi/ji/.

This phenomenon of contamination was studied here only at the rhythm of 3 to 4 syllables per second and a regular alternation of nasal and oral syllables in the proportion of 1 for 1. One of our perspectives is to study the other proportions we find in the French and other language phonological chains.

NB: The evaluation of severity of the VP incompetence by Mme Borel-Maisonny concerns only an acoustic point of view with 2 phenomena (existence of hypernasality and 3 levels of articulatory disorders) which are mostly not correlated between them and with the aerodynamic point of view.

9.4. What Is the Limit of Speed of Speech Leading to Tolerable Contaminations Between Nasal and Oral Syllables in Pathological or Healthy Individuals

Our hypothesis is three to six per second, for healthy French-speaking adults, with this proportion of 1 for 1. One of our perspectives is to study more exactly this hypothesis for that and other proportions.

9.5. Surgical Decisions

Before surgery, we have to consider:

- 1) The severity of hypernasality and inelegant nasal noise.
- 2) Above all, the alteration of the muscles’ mechanisms, whatever the extent of nasal loss: amplitude and stiffness; speed or slowness of closing/opening movements, unsteadiness of tone, irregularity, inconstancy and difficulties of programming sequences.

Among them, the main dynamic parameter to restore is the speed of VP movements in order to give the best phonological opposition of nasal /oral sounds, whatever the extent of the VP gap.

This ambition is possible thanks to a wide range of surgical procedures offered in our Center. [37, 38, 39 40, 41]

- 3) In case of Neurological Velo-Pharyngeal incompetence, often, the surgery only partially corrects the articulation disorders and the rhinolalia, but it allows better aerodynamic conditions for rehabilitation:

Even a partial decrease of nasal air loss indirectly leads to:

- 1) Increase the intra-oral pressure
- 2) A better tone of dento-labial ([f/v]) or dento-lingual ([t/d/s/z]) articulation points and a better kinesthetic feed-back to work on them;
- 3) Increase the oral air reserve, allowing prolongations of syllable sequences and thus the slowdown of speech rate.

9.6. The Measure of Nasal Air Flow During Speech

Aerophonoscope allows a semi-quantitative assessment of nasal air flow, expressed as a percentage at 80, 60, 50, 30, 20 and 100 per cent, compared to a maximal air flow objectified by nasal breath at the beginning of the examination, considered as the flow of 100 per cent for the speaker. This assessment is not sufficient for therapeutic decisions

9.7. The Opposition Between Voiced, and Unvoiced Consonants, for Healthy Individuals

Amelot describes for them that these voiced consonants are more resistant: they require less oral pressure and may lead to a slight nasal airflow.

But this notion, with aerophonoscopy is not verified in pathological individuals with hypoplastic or scarred soft palate: the voiced consonants, even if they require less oral pressure, are produced with a lesser resistance of the velopharyngeal sphincter, involving, in contrast, a greater nasal air flow

An original fact from the experiment: we noticed that the major velar leakage may lead to compensatory movements of pharyngeal constriction, for oral vowels as for nasal ones, in particular the vowel /an/ and the syllable /man/ in French.

9.8. A Dysphonia

It may be a consequence of each type of velar disorder because of the excessive Nasal Loss. The voice is sometimes distorted to such an extent that the hypernasality is not heard, and gradually reveals itself during voice rehabilitation. Here, we can say that *the feature of pathologic nasality influences the feature of voicing*.

10. Conclusions

The assessment protocol via the aerophonoscope allows us to observe directly the permeability, and indirectly the tone and movements of the velopharyngeal sphincter. So it clearly leads to a great part of the etiological diagnosis of VPI, and thus can guide surgical decisions, and rehabilitation targets.

10.1. An Ultra-Sensitive and Objective Test

The aerophonoscope provides an ultra-sensitive means of nasal air flow detection and an assessment tool for the kinetics of the VPS, revealing the characteristics of its movements: its closing capacities, its speed, acceleration/deceleration, its steadiness, its sequence programming, more than the measurement of its opening.

The aerophonoscope confirms the variable and

inhomogeneous character of nasal flow in the usual conditions of speech, especially with the striking phenomena of nasal co-articulation and of contaminations. These are absent or very moderate in normal but acute in pathological speech, whereas the perceptive assessments remain subjective.

It allows an assessment revealing the dynamics of the closing/opening movements of the velopharyngeal sphincter according to the speed of speech, to the phonetic context, during the production of facilitating or non-facilitating oral phonemes, and to phonetic sequences.

Altogether, it provides *a means of comparative assessment* based on reproducible tests during child development from 4 to 20 years old and some elderly people.

10.2. Assessment of the True Severity of Velopharyngeal Incompetence

There is no linear correlation between the extent of nasal loss and the extent of the perceptive trouble (hypernasality and/or bad intelligibility) [42]. One of the explanations of that dissociation is given to us by the aerophonoscope.

The true severity of an open rhinolalia is *not so dependent on the extent of pathological air flow*, (correlated to the magnitude of the velopharyngeal gap) *as it is on the slowness of the closing/opening of the velopharyngeal sphincter* during the alternation of oral and nasal sounds. This slowness determines the contamination phenomenon of the nasality feature and thus an inaccurate phonological opposition between oral and nasal sounds.

Otherwise, the severity of the intelligibility depends also on several factors which are linked to etiology (hearing and nasal ventilation, dental and lips occlusion, swallowing disorders, lack of intra-buccal pressure, hypotonia, apraxia, dystonias, deafness, cognitive defect added.) and so, the treatment of this poly-pathological damage has to be multidisciplinary.

We notice that aerophonoscope provides a diagnosis means for the diagnostic of bucco-facial neurologic troubles.

10.3. A Rich Semiology

It helps us to determine three aerodynamic types (dysmorphic, neurological and dysfunctional disorders) by scanning French or English language specific phonemes and syllables and by practicing the tests of "sensitization". These 3 types may be associated (mixed types), in a lot of genetic syndromes.

Each type may contribute to choose the best surgical proceedings, such as to respect at the very most the VPS physiology: "To order from Nature, we have to obey Her".

These proceedings have to reduce the VP gap and give the best amplitude, a speed and steady muscular tone (surgery of filling, lengthening, toning by muscles transpositions).

This rich semiology opens up many research perspectives. The first of them is to experiment and complete the English protocol, which is described in appendix; then we have to explore the whole of phonemes, their phonotactic links with each nasal phonemes, to go on our researches about the correlation between aerodynamic and acoustic data.

10.4. A Pleasant and Efficient Means of Rehabilitation

Thanks to a visual feedback of a part of our phonation

instrument: our nasal – and/or buccal production and our voicing or non-voicing production with a laryngeal microphone.

Appendix

Proposal of Examination Protocol of the Velo-pharyngeal Sphincter Function

With English drills (which have been used only 2 time).

Name Forename Date of Birth

Type of pathology and treatments
Genetic data
Medical history
Sensori-motor development; Tonus; Coordination Semiotic and Linguistic development

1. Influent Factors

Behaviour
Cognitive abilities
Ventilation function + daytime: Buccal or Nasal. + night time: Buccal. or Nasal; SAS: yes /no
Auditive function: -tympanum Rigt Left Audiometry: tonal threshold vocal threshold
- phonetical discrimination: - Tardieu's test - (Lafon «Phonetic tests»)
Dental occlusion Lips occlusion
Swallowing Childhood Adult mixed
Praxias in these fields: Laryngeal (X) Pharyngeal (IX) Tongue (XII) Face (VII)
1-Mimetic Praxias
2- Sequented Melokinetic praxias

2. Organic Point of View Scheme or photos. Notice compensation movements (pillars, pharyngeal constrictors)

3. Functional Point of View

3.1. Phonetism: Phonemes Structured, Sketched,

Or substituted by other phonèmes (as means of compensation or approximations)

Structured	Sketched	Substituted	Structured	Sketched	Substituted	Structured	Sketched	Substituted
[p]			[t]			[k]		
[b]			[d]			[g]		
[f]			[s]			[ʃ]		
[v]			[z]			[ʒ]		
[l]			[r]					
[h]			[j]			[θ]		

+ Phonology: - Simplification - Complexification

3.2. Dynamic Tests

3.2.1. Passive Movements: Nasal Loss

with Continuous oral blow: yes / no	with Pulsated oral blow: yes / no
-------------------------------------	-----------------------------------

3.2.2 Active Movements: % of Nasal Loss compared with maximal NL while pronunciation of /on/in French. moderate (+25%); middle (++50%); great (+++75%)

+Open v.				+Closed v.			
[p]	[t]	[k]	take up	[p]	[t]	[k]	quick, pick a tea
[b]	[d]	[g]	dog bed	[b]	[d]	[g]	A good bee
[f]	[s]	[ʃ]	Show a face	[f]	[s]	[ʃ]	She saw a fish
[v]	[z]	[ʒ]	Judge's vow	[v]	[z]	[ʒ]	Jue views a zoo
[l]	[r]		a low row	[l]	[r]		Lili a real rule
[j]	[h]	[θ]	Thine your hair !	[j]	[h]	[θ]	Hugh! You ! Thee !

3.2.3 Sensitization Tests:

Do at least the tests in bold and underlined

3.2.3.1. Basic Tonus

Holding the vowel [ou] or an altered one ([i] [u] [ʊə]): steady / unsteady

3.2.3.2. Tonus of Action

Effort tests: improvement / no improvement

Scansion, (u-u-u-): yes / no - and Glissando towards sharps (with the wolf's cry [u]): yes / no

3.2.3.3. Melokinetic Praxias

Opening and closing movements: with alternating of nasal syllable (NS) and oral syllables (OS);

1) Notice: Relative amplitude (Aggravation %) compared with the NL maximal during the nasal breath.

2) Eventual aggravation of Nasal Loss of the OS (because of contamination) 0 / + / ++

3) The closing speed: quick (< 1/3 sec.) / slow

<i>Aggravation %</i>	<i>Aggravation %</i>	<i>Aggravation %</i>
[p] pain-pain <i>Pin-pin</i>	[t] time-time <i>One tea -id</i>	[k] mankind-id <i>Monkey-monkey</i>
[b] barman- id <i>Been-been</i>	[d] Monday-id <i>Indeed-id</i>	[g] going-going <i>One gimmick</i>
[f] fan-fan <i>Fin-fin</i>	[s] same-same <i>Singing-singing</i>	[ʃ] shame-shame <i>Shimmy-shimmy</i>
[v] vain-vain <i>Viewing-id</i>	[z] zone-zone <i>Zoom-zoom</i>	[dʒ] enjoying -id <i>In June - id</i>
[r] roman-roman <i>Ringling-ringling</i>	[l] lemon-lemon <i>Loom-loom</i>	
[j] yen-yen <i>Among you -id</i>	[h] hangman-id <i>On him-on him</i>	[θ] Thine-thine <i>Thin-thin</i>

Facultative tests for the little children: 1-pronounce OS in italics (with closed vowels) 2- acceleration of the rate

4. Conclusion

4.1. Etiologie(s) of VPI and Associated Factors

4.2. Dyslalia (complete or incomplete phonetism and intelligibility): correct / medium / bad

4.3. Fonctionnal Criteria of Severity

4.3.1. Minor:

1) no Nasal Loss with oral blows;

2) soft NL while articulation;

3) Improvement in effort tests

4) No contaminations, normal speed

4.3.2. Medium:

1) NL with pulsated oral blow

2) moderate NL in articulation

3) Slight improvement in effort tests

4) Moderate contaminations, normal speed

4.3.3. High:

1) important NL with pulsated and continuous oral blows

2) significant NL in articulation

3) No improvement in effort tests

4) Frequent contaminations + Light slowness

5. Surgical Decisions

6. Proposition of Type of Surgery:

Centre de compétences des fentes labio-maxillo-palatines des Pays de Loire- France

Consultation de PHONIATRIE Dr Gabriel Rousteau

Protocole d'évaluation fonctionnelle du sphincter vélo-pharyngé

Nom Prénom D. N

1. Facteurs Influentes

Comportement

Capacités cognitives (with PM.)

Fonction ventilatoire de Jour de Nuit SAS, et occlusion labiale

Fonction auditive: -tympan

- discrimination phonétique Tests Tardieu (tests phonétiques (liste Lafon)

Fonction occlusale

Fonction déglutition laire laire mixte

Praxies bucco-faciales et paires crâniennes essentielles

Laryngées pharyngées Linguales Faciales inférieures
Pr d'imitation
Pr. Enchaînées (mélo-cinétiques)

2. *Au Plan Organique*: Schéma + Mouvements de compensation (piliers, constricteurs pharyngés, glotte, dos de la langue)
3. *Au Plan Fonctionnel*: Phrases de balayage: pour objectiver une rhinolalie fermée: "maman m'a mis au lit"

Structurée	Ebauchée	substit	Struct	Ebauch	subst	Struc	Ebauch	substituées
p		t			k			
b		d			g			
f		s			ch [ʃ]			
v		z			j[ʒ]			
l		r			ill [ij]			

- pour une rhinolalie ouverte: "flûte le fil est coupé c'est fichu"

- 3.1. *Phonétisme* + phonèmes structurés, ébauchés, substitués par autres phonèmes
+ movts compensateurs: coup de Glotte, pincement narin, Cs: laryngale (h) gutturale (kh)
+ *En combinatoire: simplification complexification*
3. 2. *Epreuves Dynamiques* à l'Aérophonoscope
3.2.1. *Mobilisation Passive*: Déperdition Nasale (DN): oui ou non

Souffle continu: Oui Non	Souffle pulsé: Oui Non
--------------------------	------------------------

3.2.2. *Mobilisation Active*: DN en % par rapport à la fuite maximale à l'émission du /on/ modérée (+ 25%); moyenne (++)50%); importante (++++)75%)

a	è	o		u	é	i	ou	eu
pa	Ta	Ka	Toi t'es cap, coca	Pi	Ti	Ki	Tu piques hé	
Ba	Da	Ga	Des bagues	Bi	Di	Gui	bigoudi	
Fa	Sa	Cha	(Elle) se facha	Fi	Si	Chi	Cé fichu	
Va	Za	Ja	Je vais au zoo	Vi	Zi	Ji	J'é vu zizou	
La	Ra	Ya	L'oreille	Lé	Ré	yé	Riez lili	leur

3.2.3. *Epreuves de Sensibilisation*

Faire au minimum les épreuves en gras et soulignées

3.2.3.1. tonus de fond: stable / instable

3.2.3.2. tonus d'action: épreuves d'effort sur les voyelles déviantes (par ex. /u/, /ou/): amélioration: oui/non

+ Scansion, u-u-u-u: oui non + Glissando vers les aigus (le cri du loup pour /ou/) oui non

3.2.3.3. Praxies enchaînées: mouvements de fermeture/ ouverture à dessiner ou à imprimer

en alternant les syllabes Nasales (SN) et les syllabes Orales (SO), peu contrastées

en redoublant les SO, afin d'accentuer les consonnes au rythme de la langue française.

On note:

- 1) l'existence d'une aggravation des Déperditions Nasales des différentes SO
(par contaminations constantes ou par une "accélération") 0 ++
- 2) l'amplitude relative (A%) des mouvements de Fermeture/Ouverture par rapport au respir nasal
- 3) la vitesse de fermeture rapide (< 1/3 sec.) lente

-Aggrav- A%	-Aggrav -A%	-Aggrav- A%
/p/: mon papa pei-peigne <i>piment</i>	/t/: Mon-toto <i>mon toutou</i>	/k/: Mon coco; <i>Mon coucou</i>
/b/: mon bobo <i>Bidon; buvons</i>	/d/: do-donnons <i>Dis donc</i>	/g/: gogo-mons <i>guidon</i>
/f/: Faifai--sons <i>m'en fous mon fou</i>	/s/: Sau-saumon <i>- simon</i>	/ch/: chochomon <i>chignon</i>
/v/: Vovo-lons <i>- nous visons</i>	/z/: Ns aimons, <i>- Nous irons</i>	/j/: mon jojo <i>- Mon joujou; jument</i>
/r/: Ray ray mond <i>-Nous Rions</i>	/l/: mon/lait-lait; <i>nous lisons</i>	/y/: Mon Yo yo <i>-You you and me</i>

Epreuves facultatives: tests avec les SO en italique comprennent des voyelles fermées

Pour les petits: mon papa, mon coco, mon toto, mon baba(r), mon dodo, mon gars-gars, mon foufou, mon seau-sot, mon chat-chat; m'en vais-vaïs; mon jojo; mon zozo; mon raton, mon lot-lot; mon yoyo

4. Conclusion

- 4.1. Type étiologique de VPI et facteurs associés
- 4.2. Dyslalie (phonétisme complet / incomplet) et intelligibilité globale: correcte / acceptable / mauvaise
- 4.3. Critères fonctionnels de Sévérité
 - 4.3.1. - Légère
 - 1) pas de DN aux souffles;
 - 2) DN légères à l'Articulation des phonemes
 - 3) amélioration à l'effort
 - 4) vitesse rapide; pas de contamination
 - 4.3.2. - Moyenne
 - 1) DN au souffle pulse
 - 2) DN modérée (+) à l'articulation
 - 3) peu d'améliorat° à l'effort
 - 4) vitesse rapide et contaminations modérées
 - 4.3.3. - Sévère:
 - 1) - DN au souffle continu et pulsé;
 - 2) DN fréquentes à l'articulation
 - 3) -sans améliorat° à l'effort
 - 4) vitesse lente et contaminations fréquentes
5. *Décisions Chirurgicales*
6. *Orientations Chirurgicales Suggérées*

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