

## ***Normative nasalance scores for French-speaking children in Quebec: A tale of two cities***

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## **Abstract**

*Objective:* To establish normative nasalance scores for the Nasometer II for children speaking Quebec French.

*Design:* Prospective study using a randomly selected sample of children with typical speech.

*Setting:* Two children's hospitals in the province of Quebec, Canada.

*Participants:* Eighty-eight children with typical speech, language and hearing development, aged between 6;0 and 11;11 years, were enrolled at the [Center 1] in Montreal and the [Center 2] in Quebec City, Canada.

*Outcome Measure:* Mean nasalance scores

*Results:* Mean nasalance scores were obtained for oral vowels, nasal vowels, repeated syllables, oral sentences, nasal sentence, and a mixed sentence. While there were no meaningful significant effects of sex and age on the nasalance scores, most nasalance scores obtained at the hospital site in Montreal were statistically significantly higher than in Quebec City. Mean nasalance scores, standard deviations and theoretical critical threshold values are provided and can be used for clinical assessment and research.

*Conclusions:* Nasalance scores differences according to hospital sites may be attributable to dialectal differences, to differences between the nasalance scores obtained by the Nasometers in the two clinics, or to a combination of the two. In future research, diagnostic cutoff scores for different nasal resonance disorders can be developed based on these normative scores.

**Keywords:** nasalance scores, Nasometer II, speech assessment, nasality, cleft palate

## **Introduction**

In the field of Speech-Language Pathology, resonance refers to our perception of the vibration of sound through the oral, pharyngeal and nasal cavity<sup>1,2</sup>. The sound frequencies generated by the vocal folds are modified by the shape and size of the air space of the vocal tract, which in turn are modified by articulatory settings such as the position of the tongue, the opening of the mouth and the opening and closing of the velopharyngeal valve<sup>3</sup>. The velopharyngeal valve is responsible for coupling and decoupling the oral and nasal cavities during speech. During velopharyngeal closure, the velum elevates and the nasopharynx narrows<sup>4</sup>. Velopharyngeal closure is important for the production of oral speech sounds, while nasal and nasalized speech sounds are produced with an open velopharyngeal sphincter. The proper functioning of the velopharyngeal sphincter is essential for intelligible and acceptable speech.

In Speech-Language Pathology, the term *resonance disorder* is used to refer to imbalances of oral and nasal resonance in speech<sup>5</sup>. There are different resonance disorders, or types of oral-nasal imbalances, that may arise as a result of anatomical and functional differences<sup>6</sup>. Hypernasality is defined by excessive nasal resonance on voiced oral vowels and consonants. The cause is velopharyngeal dysfunction (VPD), which may be due to anatomical defects (e.g. cleft palate), motor impairment (e.g. dysarthria) or velopharyngeal mislearning (e.g. compensatory articulation error despite adequate anatomical structures). Hyponasality manifests when there is not enough sound transmitted through the nasal cavity on nasal sounds. This results from nasal airway obstruction, such as hypertrophic adenoids and tonsils or septum deviations. Mixed resonance manifests when there is hypernasality present on oral consonants together with hyponasality on nasal consonants. This phenomenon may arise in cases of combined velopharyngeal dysfunction and partial nasal obstruction<sup>5</sup>. Individuals affected by a resonance disorder may experience differing levels of impact on the intelligibility and acceptability of their speech. This may lead to social challenges and poorer psychosocial outcome<sup>7</sup>.

Auditory-perceptual assessment performed by a trained speech-language pathologist is considered best practice to assess for speech and resonance disorders<sup>6</sup>. To supplement listeners' auditory-perceptual evaluations, the Nasometer enables a non-invasive, quantitative assessment of nasalance, which is a proxy measure for the balance of oral and nasal resonance. The nasalance

score is the ratio of nasal acoustic energy to the sum of nasal and oral acoustic energy. Nasometers have been used in clinical practice and research for over thirty years<sup>5,8-10</sup>. In addition to providing a quantitative measure, nasalance assessment can help determine the effectiveness of speech therapy or surgical intervention and may assist clinicians in judging the degree of severity of a nasal resonance disorder by comparing a patient's results with the norms established for children of the same age and region. This measure adds a distinctive feature to speech results and is complementary to other objective measures that can be obtained using videofluoroscopy or nasoendoscopy. Nasalance can be an important component of the comprehensive diagnosis of nasal resonance disorders in speakers with cleft lip and palate.

Normative nasalance scores can vary between different languages<sup>10,11</sup> and even dialects<sup>12,13</sup>. There are also effects of age<sup>14-18</sup> and possibly of sex<sup>17-21</sup>. Finally, different speech stimuli will result in different nasalance scores<sup>22-24</sup>. While standard stimuli for nasalance testing have been developed for many different languages, the situation is still more heterogeneous when it comes to French. Stimuli and normative nasalance scores have been developed for adult<sup>25,26</sup> and paediatric speakers of Swiss French<sup>11</sup>. In Canada, stimuli and reference scores have been established for minority French-speaking children and young adults in the Canadian West<sup>12,27</sup>. However, there are currently no well-researched test materials and normative scores for children in Quebec, which is a majority French-speaking province in Canada. Quebec French has a different pronunciation for vowels than European French<sup>28-32</sup>. It is also characterized by longer nasal vowels. In addition, these tend to become diphthongized in closed stressed syllables<sup>33,34</sup>.

Therefore, the primary objective of this study was to obtain nasalance norms for French-speaking children in Quebec aged 6-11 years. The secondary objective was to explore the possible differences between mean nasalance scores according to sex, age and research sites. These research objectives were explorative, and explicit research hypotheses were not considered necessary or helpful in this context.

## Methods

### Participants

Research ethics were obtained for a multi-site data collection (# MP-21-2017-1357). The data collection took place between 2017 and 2020. A total of 104 children with typical speech were screened for participation in the study at two academic children's hospitals in Quebec. Sixty-nine children were screened at the [Center 1] and 35 at the [Center 2]. For inclusion, patients had to be between 6 to 11 years old, speak age-appropriate Quebec French as their first and dominant language as well as pass a hearing screening (1000Hz, 2000Hz and 4000Hz). Exclusion criteria included craniofacial and dentofacial differences, speech and language disorders, developmental disorders, and attentional or behavioural problems. Sixteen participants failed the initial screening. The resulting study group was composed of 88 children (44 girls and 44 boys). Of these participants, 59 were recruited at the [Center 1] (24 girls and 35 boys) and 29 at the [Center 2] (20 girls and 9 boys). The mean age was 8.75 years (SD = 1.68). All children spoke Quebec French as their first language, but 11 also spoke English and five spoke Arabic at home.

### **Speech stimuli**

A short protocol consisting of a variety of stimuli has been developed and pre-tested<sup>35</sup> for the assessment of nasalance in Quebec French. The stimuli were chosen to capture a variety of phonetic features and to enable comparison with already existing research data for French, namely those of Leeper et al.<sup>12</sup>, Garnier<sup>25</sup> and Tourmel<sup>26</sup>. Some of these stimuli are part of a recently published list of sentences in Quebec French for the auditory-perceptual assessment of resonance and speech related to velopharyngeal function<sup>36</sup>. The protocol includes 28 stimuli in various contexts: six prolonged isolated vowels, 13 repeated syllables, eight sentences and one reading passage with 73 words. The reading passage was limited to participants aged 8 to 12 to ensure fluent reading. Table 1 shows the stimuli included in the assessment protocol.

**[INSERT TABLE 1 HERE]**

### **Materials**

Hearing screening was performed using an Interacoustics AA222 portable audiometer at [Center 1] and a MAICO MA25 ANSI S3.6 Class 4 audiometer at [Center 2]. Nasalance data were collected using the PENTAX Medical Nasometer II (model 6450). Each site had its own nasometer. Following

the manufacturer's recommendations, each device was calibrated at the start of the day. An additional calibration was carried out in the middle of the day.

### **Procedure**

The assessments were conducted in the offices of the Speech-Language Pathology department at each site, providing a calm and noise-free environment. Speech and hearing were screened first. For the speech screening, the task was a spontaneous conversation, with informal assessment tasks such as a picture description, if necessary. Nostril patency was screened using a nasal mirror. Screening was considered successful when the speech-language pathologist judged that there were no speech anomalies or signs of nasal obstruction. A hearing screening was then performed. Following the guidelines of the American Academy of Audiology<sup>37</sup>, three frequencies were tested at an intensity of 20 dB for each ear: 1000 Hz, 2000 Hz and 4000 Hz. Screening was considered successful when the child had detected two out of three signals for each frequency tested, for each ear.

Once a child was deemed eligible to take part in the study, the nasometer assessment could begin. The nasometer headset was placed on the participant's head according to the manufacturer's recommendations. Monitoring was carried out throughout the assessment to ensure that the headset remained properly positioned. Once the headset was positioned, the participant was asked to repeat the various stimuli of the assessment protocol. The order of the stimuli was counterbalanced to ensure that each participant experienced the stimuli in a different sequence, minimizing any potential bias or order effects.

Breaks were allowed whenever a participant needed them. If the child made a mistake, he or she was asked to repeat the stimulus until it was produced correctly. Nasalance scores for each stimulus were recorded for later analysis.

### **Data analysis**

To establish the nasometry norms for children speaking Quebec French, the data were analyzed descriptively with mean nasalance scores and standard deviations. In the diagnosis of resonance disorders, elevated nasalance scores for oral speech stimuli are considered an indication of hypernasality while excessively low nasalance scores on speech stimuli loaded with nasal sounds are an indication of hyponasality<sup>1</sup>. Kummer<sup>38</sup> estimated that the borderline region for hypernasality begins two standard deviations above the mean score of an oral test stimulus. For hyponasality, the same author estimated the borderline region more conservatively one standard deviation below the mean for a nasal speech stimulus. In the present study, this method was used to estimate the critical thresholds for nasalance scores that could be considered too high for oral speech stimuli and too low for nasal speech stimuli.

The nasometric norms for Quebec French were created with a data collection that was carried out with young female and male speakers ranging in age from 6 to 11 years. The data were also collected at two sites, with different nasometers. As a result, it was important to investigate possible effects of speaker sex, age and sites. To investigate the possible effect of age on the nasalance scores, the group was divided into one group of 51 children aged 6-8 years (24 girls and 27 boys) and a second group of 37 children aged 9-11 years (20 girls and 17 boys) for statistical testing.

Not all children were able to complete all recordings of the test materials. Based on the data distribution for each stimulus, statistical testing was carried out either with Student T-tests or non-parametric Mann-Whitney U-tests, as appropriate. While this resulted in a relatively large number of 84 two-sided comparisons, the significance level was not Bonferroni-adjusted to avoid Type II false-negative errors<sup>39</sup>. Exact p values were recorded so that the plausibility of the described differences could be better appreciated. The significance level was set at  $p < 0.05$ . The statistical analyses were carried out in SAS 9.4 and NCSS 8.

## Results

The combined statistical results from the two sites can be found in the respective columns in Tables 1-4. Together with the means and standard deviations, the theoretical critical threshold (CT) of two standard deviations above the mean for oral stimuli and of one standard deviation below the mean for nasal stimuli, as suggested by Kummer<sup>38</sup>, are also reported.

The average nasalance score for all oral vowels was 14.12%. The highest nasalance score was obtained for the vowel /i/ (26.32%) and the lowest for the vowel /o/ (7.58%). For nasal vowels, the average nasalance score was 56.86%. The highest nasalance score was obtained for the vowel /ɛ/ (62.84%) and the lowest for the vowel /ɔ/ (50.88%). For repeated monosyllables, the average nasalance score was 34.95%. The highest nasalance score was obtained for the /mi/ (85.23%) and the lowest for the /ja/ (8.93%). In general, the highest nasalance scores were obtained for monosyllables that contained a nasal consonant. For the oral sentences, the average nasalance score was 15.46%. The phrase "Gigi a la luge" had the highest nasalance score (19.64%) while the phrase "Papa paie la loupe" had the lowest (10.00%). The nasalance score for the nasal sentence was 53.71%. For the phonetically mixed sentences, the average nasalance score was 27.20%. The sentence "Elle aime bien le chocolat" had the highest nasalance score (29.90%) and the sentence "Il plante des sapins" the lowest (24.50%). Finally, for the mixed text ("Le petit prince"), the nasalance score was 30.25%.

Statistical testing showed no significant differences between boys and girls, with the exception of the phonetically mixed sentence "Elle aime bien le chocolat" (girls mean 28.12, SD 7.56 vs. boys mean 31.86, SD 7.81;  $p = 0.0100$ ).

When the data for children in the age group 6-8 were compared to the age group 9-11, there were no significant differences except for the repeated syllable /mi/ (children 6-8 mean 84.39, SD 5.04, vs. children mean 9-11 86.38, SD 4.76;  $p = 0.0465$ ).

When the data for the speakers were compared by centre, it was found that the nasalance scores for stimuli recorded at the Montreal site [Center 1] were always numerically higher than at the Quebec City site [Center 2], except for the two repeated syllables /kã/ and /dã/. Statistical testing showed that the nasalance scores for 15 out of the 28 stimuli (53.60%) were significantly higher at the [Center 1]. Therefore, the descriptive reporting in Tables 2-5 breaks up the results by centre.

**Table 1 : Stimuli**

Vowels (n = 6)	/i/, /u/, /a/, /o/, /ɛ/, /ě/
Repeated monosyllables (n = 13)	/pi/, /ta/, /kã/, /ba/, /bi/, /dõ/, /ʃa/, /ʒi/, /za/, /zi/, /ma/, /mi/, /nẽ/
Sentences (n = 8)	Papa paie/paye la loupe <sup>1</sup> ; La doudou est laide <sup>1</sup> ; Ce loup a sucé la suce <sup>1</sup> ; Gigi a la luge <sup>1</sup> ; Wow! Louis a le yoyo <sup>1</sup> ; Maman aime le miel <sup>1</sup> ; Elle aime bien le chocolat <sup>2</sup> ; Il a planté des sapins <sup>2</sup> .
Reading passage (n = 1)	Un jour, le Petit Prince a rencontré le vendeur de kiwis. Bonjour, dit le vendeur. Tu veux de mes kiwis? Ce sont des kiwis qui apaisent la soif. C'est pratique et économique. On gagne douze minutes par jour au moins, tout le temps qu'on passerait à boire. Et le Petit Prince a répondu : Moi, si j'avais douze minutes de libres par jour, je les prendrais pour marcher tout doucement vers une fontaine... <sup>3</sup>

<sup>1</sup>Sentence from Caty et al.'s<sup>36</sup> list of sentences in Quebec French for auditory-perceptual assessment of resonance and speech related to velopharyngeal function.

<sup>2</sup> Sentence from Garnier<sup>25</sup> and Tourmel<sup>26</sup> nasalance evaluation protocol.

<sup>3</sup> Adapted from Leeper et al.<sup>12</sup>

**Table 2: Mean Nasalance Scores for Vowels**

Stimulus	Context	Combined normative score Mean (SD)	[Center 1] Mean (SD)	[Center 2] Mean (SD)	p-value
/i/	Oral	26.32 (11.18) CT > 48.68 N = 87	26.59 (9.81) n = 59	25.75 (13.82) n = 28	ns
/u/	Oral	13.97 (7.67) CT > 29.17 N = 87	14.17 (6.79) n = 59	13.54 (9.37) n = 28	ns
/a/	Oral	8.61 (6.65) CT > 21.91 N = 88	9.24 (7.55) n = 59	7.34 (4.09) n = 29	ns
/o/	Oral	7.58 (5.72) CT > 19.02 N = 88	7.90 (6.37) n = 59	6.93 (4.13) n = 29	ns

/ɔ/	Nasal	50.88 (15.50) CT < 35.38 N = 88	54.90 (16.26) n = 59	42.69 (9.79) n = 29	0.0007***
/ě/	Nasal	62.84 (9.74) CT < 53.1 N=88	64.63 (8.55) n = 59	59.21 (11.09) n = 29	0.0066***

Legend: ns P > 0,05, \* P ≤ 0,05, \*\* P ≤ 0,01, \*\*\* P ≤ 0,001

**Table 3: Mean Nasalance Scores for Repeated syllables**

Stimulus	Context	Combined normative score Mean (SD)	[Center 1] Mean (SD)	[Center 2] Mean (SD)	p-value
/pi/	Oral	20.66 (8.10) CT > 36.86 N = 87	21.29 (7.99) n = 59	19.32 (8.30) n = 28	ns
/ta/	Oral	9.32 (3.28) CT > 15.88 N = 78	10.19 (3.27) n = 54	7.38 (2.36) n = 24	0.0003***
/kã/	Nasal	50.30 (12.88) CT < 37.42 N = 88	49.00 (13.13) n = 59	52.93 (12.15) n = 29	ns
/ba/	Oral	10.75 (6.06) CT > 22.87 N = 88	12.31(6.69) n = 59	7.59 (2.43) n = 29	0.0002***
/bi/	Oral	25.00 (11.53) CT > 48.06 N = 88	26.76 (11.56) n = 59	21.41 (10.80) n = 29	0.0170*
/dɔ/	Nasal	46.73 (10.35) CT > 67.43 N = 79	42.20 (9.88) n = 54	45.72 (11.46) n = 25	ns
/ʃa/	Oral	8.93 (6.51) CT > 21.95 N = 80	9.60 (7.39) n = 58	7.14 (2.53) n = 22	0.0400*
/ʃi/	Oral	21.13 (7.86) CT > 36.85 N = 83	22.07 (8.05) n = 58	18.96 (7.07) n = 25	ns
/za/	Oral	11.40 (4.11) CT > 19.62 N = 78	12.26 (4.18) n = 54	9.46 (3.26) n = 24	0.0047**
/zi/	Oral	25.34 (9.08) CT > 43.50	26.72 (8.72)	22.36 (9.30)	0.0183*

		N = 79	n = 54	n = 25	
/ma/	Nasal	61.31 (8.87) CT < 52.44 N = 88	63.34 (8.33) n = 59	57.17 (8.62) n = 29	0.0015**
/mi/	Nasal	85.23 (5.00) CT < 80.23 N = 88	85.41 (5.00) n = 59	84.86 (5.06) n = 29	ns
/nẽ/	Nasal	72.58 (6.97) CT < 65.61 N = 79	73.76 (6.85) n = 54	70.04 (6.66) n = 25	0.0193*

Legend: ns P > 0,05, \* P ≤ 0.05, \*\* P ≤ 0.01, \*\*\* P ≤ 0,001

**Table 4: Mean Nasalance Score for Sentences**

Stimulus	Context	Combined normative score Mean (SD)	[Center 1] Mean (SD)	[Center 2] Mean (SD)	p-value
Papa paie/paye la loupe.	Oral	10.00 (3.77) CT > 17.54 N = 77	10.59 (3.99) n = 54	8.61 (2.81) n = 23	0.0305*
La doudou est laide.	Oral	18.46 (7.73) CT > 33.91 N = 78	20.13 (7.71) n = 54	14.71 (6.46) n = 24	0.0014**
Ce loup a sucé la suce.	Oral	13.77 (5.50) CT > 24.76 N = 78	14.31 (5.55) n = 54	12.54 (5.29) n = 24	ns
Gigi a la luge.	Oral	19.64 (7.57) CT > 34.78 N = 79	20.89 (7.49) n = 54	16.96 (7.16) n = 25	0.0051**
Wow! Louis a le yo-yo.	Oral	15.44 (7.54) CT > 30.52 N = 79	16.31 (7.74) n = 54	13.56 (6.87) n = 25	0.0444*
Maman aime le miel.	Nasal	53.71 (8.33) CT < 45.38 N = 78	55.57 (8.11) n = 53	49.76 (7.50) n = 25	0.0034**
Elle aime bien le chocolat. <sup>1</sup>	Mixed	29.90 (7.55) N = 78	31.00 (8.15) n = 53	27.56 (5.55) n = 25	ns
Il a planté des sapins. <sup>1</sup>	Mixed	24.50 (7.04) N = 78	25.23 (7.23) n = 53	22.96 (6.48) n = 25	ns

<sup>1</sup> Sentence taken from Garnier (2012) and Tournel (2012).

Legend: ns P > 0,05, \* P ≤ 0.05, \*\* P ≤ 0.01, \*\*\* P ≤ 0,001

**Table 5 : Mean Nasalance Scores for the Text**

Stimulus	Context	Combined normative score Mean (SD)	[Center 1] Mean (SD)	[Center 2] Mean (SD)	p-value
Le petit prince	Mixed	30.25 (5.70) N = 40	31.62 (5.66) n = 26	27.71 (5.00) n = 14	ns

Legend: ns P > 0,05, \* P ≤ 0.05, \*\* P ≤ 0.01, \*\*\* P ≤ 0,001

## Discussion

The present study established new stimuli as well as the first norms for nasalance scores for French-speaking children in Quebec aged 6;00-11;11 years. These can now be used by speech-language pathologists to assess children with resonance disorders who speak Quebec French. The overall results demonstrated that the stimuli worked as intended, with high nasalance scores for items loaded with nasal sounds, low scores for non-nasal stimuli, and nasalance scores in-between the extremes for the phonetically balanced materials.

Together with the mean scores, theoretical critical threshold values were reported for each item according to the method suggested by Kummer<sup>38</sup>. However, these authors also emphasized that such thresholds are only approximate and that occasional normal speakers may straddle these boundary areas. While many of the reported estimated critical threshold scores appeared plausible, items such as the repeated syllables /ma/ and /mi/ had high mean scores with low standard deviations, so that the resulting theoretical critical thresholds were unrealistically high. The same observation could be made about the oral sentence “Papa paie la loupe”, which had the lowest nasalance scores of all the sentences. As a result, the estimated critical threshold was still lower than the mean nasalance scores of some of the cognate oral test sentences in this collection. Future research will be needed to determine more accurate cut-off scores for the test stimuli.

A direct comparison of the present data set with other previous data collections in French<sup>11,12,25–27</sup> was not possible because of the differences in testing materials, French dialects and generations of nasometers used. Watterson<sup>23</sup> argues that, in general, nasalance scores lower than 20% for oral test sentences or texts can be considered typical. Dalston, Warren and Dalston<sup>40</sup> first suggested a cut-off of 32% for hypernasality but then revised the cut-off to 28% in a later study<sup>41</sup>. Hardin et al.<sup>42</sup> argued for a lower threshold of 26%. Based on a review of different studies, Watterson<sup>23</sup> suggested 30% as the cut-off for hypernasality, a range of 31-45% for mild to moderate hypernasality, and over 45% for severe hypernasality. For sentence- or text-level speech stimuli loaded with nasal sounds, a threshold lower than 50% nasalance has been suggested as the diagnostic limit for hyponasality<sup>42,43</sup>. Future research will have to demonstrate whether the cutoff scores for Quebec French would fall into similar ranges.

With the collection of the normative nasalance scores, it was also important to investigate possible effects of speaker sex, age and research sites. Between boys and girls, only one mixed sentence out of the 28 (3.6%) test items showed a significantly higher nasalance score for the boys. When the data for children in the age group 6-8 were compared to the age group 9-11, only one nasal syllable out of 28 (3.6%) test items had significantly higher nasalance scores for the group of older children. In both cases, the mean scores for the two groups were still within a few nasalance points of each other, so it is difficult to attach a particular meaning to these two isolated findings.

There were more systematic differences between the two centres. Almost all (26 out of 28, or 93%) nasalance scores for the stimuli recorded at the [Center 1] were numerically higher. For the 15 out of 28 (53.6%) items where significant differences were found, many of the p values were small, so these differences can probably be considered meaningful despite the large number of statistical tests.

The differences in nasalance scores between the two sites may be attributable to dialectal differences between the cities of Montreal and Quebec, to differences between the nasalance

scores obtained by the nasometers in the two clinics, or to a combination of the two. It is possible that dialectal differences could explain the differences between the two centers. In previous research, dialectal differences have been found to affect nasalance scores in different varieties of North American English [19] and Flemish [20]. Canadian French has many regional dialectal varieties. The interested reader may listen to audio examples from the two regions in the publicly available “Atlas sonore des variétés de français au Canada”<sup>44</sup>. The differences between Montreal and Quebec City French are subtle. While they may be recognizable to speakers of Québécois French, the distinction may be more difficult to make for speakers of other varieties of French. The main differences relate to features such as vocabulary or vowel length differences<sup>45</sup>. French in the Province of Quebec is known for its phonological opposition between intrinsically short and intrinsically long vowels. For some words, this difference may even signal that the speaker comes from a specific region: French in the Montreal area generally has longer vowels, while that of the Quebec City area has shorter vowels<sup>45</sup>. Given that the nasometer measures nasalance mainly through vowels because of its bandpass filtering characteristics<sup>8</sup>, then longer nasalized vowels in one dialect could presumably lead to higher nasalance scores. This could explain the higher nasalance scores recorded at the [Center 1], located in Montreal.

The observed differences may also result from the nasometers itself. The study was conducted at two different sites, and with two different nasometers of the 6450 type. When Bressmann and Tang<sup>46</sup> compared nasalance scores obtained with four different nasometer headsets, they found that between 56.1% to 98.9% of measurements were within 3 nasalance points for the different pairs of headsets. The largest difference observed was 8 nasalance points. Unfortunately, the nasometers in the current study had been retired and the headsets could not be compared to verify whether the higher scores at the [Center 1] site were attributable to the specific characteristics of the microphones in the headset used at this site.

### **Limitations**

The present study had several limitations that should be considered when interpreting the findings. Some of the test sentences were quite short. This was done deliberately to ensure that

they could be read or repeated even by very young or preliterate children. In general, the nasalance scores obtained with short stimuli can be equivalent to those obtained with longer text passages<sup>47</sup>. However, a few sentences were shorter than the minimum length of six syllables as recommended by Watterson, Lewis and Foley-Homan<sup>24</sup>. This could potentially increase the variability of the nasalance scores obtained with these test stimuli.

In the statistical analysis, numerous inferential tests were computed. This was considered a prudent approach because of differences in the number of speakers and the nature of the data distributions for the different test items. The statistical findings showed that many of the nasalance data recorded at the [Center 1] in Montreal were significantly higher than at the [Center 2] in Quebec City, which was considered a plausible finding. For the two isolated findings for sex and age, it was more difficult to decide whether these were meaningful differences or spurious statistical effects. Finally, it could not be conclusively resolved whether the higher nasalance scores at the CHUSJ site were the result of dialectal differences or of measurement differences between the nasometers used. However, it was also important to ensure that the norms represented paediatric speakers of Quebec French from different geographical regions.

## **Conclusion**

This study developed normative nasalance scores data for French-speaking children in Quebec aged between 6;0 to 11;11 years old. These normative scores can now be used by speech-language pathologists working with French-speaking pediatric patients with craniofacial conditions such as cleft palate, as well as with children with speech disorders related to velopharyngeal dysfunction of other origin. With normative scores, the nasometer can be better used to corroborate clinicians' auditory-perceptual assessments, to support the team in making treatment decisions for the patient, and to measure a patient's progress following speech therapy or surgery.

The variety of test items with normative scores presented here provides the clinician with a range of options for testing clients with different linguistic or developmental abilities. The assessment can be adapted to the clinician's needs and the child's characteristics.

In future research, the assessment protocol will be used with speakers with resonance disorders – i.e. oral-nasal imbalances – in order to establish reliable diagnostic cut-off scores for hypernasality and hyponasality for children speaking Quebec French.

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### **Declaration of Conflict of Interests**

The authors have no conflicts of interest to declare.

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### **Ethical approval and informed consent statements**

This multi-site study protocol was reviewed and approved by Comité d'éthique de la recherche, CHU Sainte-Justine, approval number # MP-21-2017-1357. Written informed consent was obtained from the parents of the children participating in the study.

## **Data availability Statement**

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

## **Author Contributions**

All authors contributed to the research and preparation of this manuscript. Marie-Eve Caty was instrumental in the conceptualization, methodology development and supervision of the study, in collaboration with all the other authors. Annie Salois, Andréanne Mayrand and Ericka Beaudoin obtained funding, collected the data together with their team members and administered the project at their respective sites. Tim Bressmann helped with the analysis and interpretation of the study findings. All authors contributed to the writing and editing of the manuscript.

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## **List of figure legends**

### **Table 1 : Stimuli**

Table 1 shows the stimuli included in the assessment protocol.

### **Table 2: Mean Nasalance Scores for Vowels**

The descriptive reporting in Tables 2 breaks up the results by centre for the vowel stimuli.

### **Table 3: Mean Nasalance Scores for Repeated Syllables**

The descriptive reporting in Tables 3 breaks up the results by centre for the repeated syllables stimuli.

### **Table 4: Mean Nasalance Score for Sentences**

The descriptive reporting in Tables 4 breaks up the results by centre for the sentences stimuli.

### **Table 5 : Mean Nasalance Scores for the Text**

The descriptive reporting in Tables 5 breaks up the results by centre for the text stimulus.