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# Nasalance scores of Thai cleft palate children using the Thai Simplified Nasometric Assessment Procedures Test (Thai SNAP Test)

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## ABSTRACT

**Background:** Nasometry in children with cleft lip and/ or palate (CLP) aged 4-6 years is necessary for diagnosis and planning treatments to promote decreasing velopharyngeal insufficiency (VPI) or resonance disorders that affect good speech intelligibility, prevent compensatory errors and other speech and language problems. Most Thai nasometric speech stimuli are passages suitable for literate patients. Using nasometric passages in young children who cannot read takes a long time to complete and gives unreliable nasalance scores. Due to the limitations, The Thai Simplified Nasometric Assessment Procedures Test (the Thai SNAP Test) was developed and assessed for validity and reliability, revealing that the Thai SNAP Test is proper for evaluating the speech resonance of illiterate patients. However, there is no study on nasometry in children with repaired cleft lip and/ or palate (RCLP) using the Thai SNAP Test.

**Objectives:** To study nasalance scores between the control (non-cleft) group and the RCLP group assessed by the Thai SNAP Test and to describe the influential factors that affected nasalance scores.

**Materials and methods:** The subjects were Thai children aged 4-7. The two groups of children were the RCLP and the control groups, and 36 children in each group. Nasalance scores were measured by a Nasometer II (model 6450). The child was asked to repeat 25 speech stimuli from the Thai SNAP Test, and then the scores were computed using a t-test or Mann-Whitney U test, depend on data distribution. The mean difference in nasalance scores between the two groups and the 95% Confident Interval (95% CI) were analyzed by the two-sample t-test with equal variances and the bootstrap confidence interval method, respectively.

**Results:** The nasalance scores of the RCLP group were significantly higher than the control group ($p<0.05$) when using high-pressure oral speech stimuli. However, using nasal speech stimuli, the RCLP group's nasalance scores were significantly lower than the control group ($p<0.05$), except for nasal syllable repetition (/na/ and /ni/), which did not find a significant difference ($p\geq0.05$). This study emphasized that influential factors for the difference in the nasalance scores between the two groups were abnormal structures and functions articulators, especially the velopharyngeal port that was affected by the CLP, which caused resonance disorders, misarticulations, voice disorders, obstruction in the vocal tract, and hearing impairment. However, the phonological features used in the speech stimulus caused the difference in the mean nasalance scores of the same group.

**Conclusion:** The trends in nasalance scores suggested that the Thai SNAP Test could identify speech resonance disorders in Thai children aged 4-7. The speech and language pathologist (SLP) or evaluator should consider factors influencing the nasalance scores. For accurately diagnosing or evaluating the progression of treatments, nasalance scores from Nasometer should be applied together with other information from various methods or instruments.

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**Introduction**

Nasometry is one of the most popular methods of speech resonance assessment. Nasometry is a non-invasive instrument that measures the acoustic energy from oral and nasal cavities; then, a microcomputer in a nasometer computes the data and gives numerical data called nasalance scores. Nasalance scores are the results of oral acoustic energy divided by oral and nasal acoustic energy and then multiplied by 100, shown in the percentage. The mean nasalance scores were used to represent the scores of each speech stimulus.[1]

Pediatric nasometry is essential and needs reliable results for accurate diagnosis and treatment. However, speech and language pathologists (SLPs) frequently confront problems while assessing nasalance scores. One of the critical problems is nasometric passages, which are long and composed of complex words that are hard to understand and produce correctly, causing an extended period of nasometry and resulting in unreliable nasalance scores.[1,2] Passages and duration of nasometry are inappropriate for illiterates, patients who cannot tolerate wearing a headset, or with limited attention spans.[1]

From these limitations, Kummer modernized the SNAP Test, named the MacKay-Kummer Simplified Nasometric Assessment Procedures Test Revised 2005 (the SNAP Test-R), and re-normed using a Nasometer II in 246 American children without speech and language problems aged 3-9 years.2 Because the SNAP test-R is easy to use, gives reliable results, does not require reading skills, and can select some items, so a patient can produce and relate to suspected resonance problems.[1,2] The Test was adapted to other languages, such as Turkish, Persian, and Thai.[3-5]

In Thai, Liadprathom developed the Thai Simplified Nasometric Assessment Procedures Test (Thai SNAP Test) based on the SNAP Test-R, including speech sound selection, assessment processes, and instructions.[5,2] Consonants selection considered the sound acquisition of Thai children.[6] The content validity and reliability of Thai SNAP test were analyzed in 51 children aged 4-6 years who speak central Thai and have age-appropriate speech and language development. The results showed excellent accuracy and a high correlation coefficient of test-retest reliability, indicating that Thai SNAP Test is valid for evaluating speech resonance in children aged 4-6 years. With a test of 2 subtests (25 speech stimuli), Thai SNAP Test includes the syllable repetition/ prolonged sound subtest I and the picture-cued subtest II.[5]

The literature review found that many studies compared the nasalance scores of the RCLP and the non-cleft groups using the SNAP Test or simple nasometric speech stimuli (syllables, words, or simple sentences). Most studies reported that the scores of the RCLP group were significantly higher than those of the control group when using oral speech stimuli but could not find a significant difference when using nasal speech stimuli [7-10] and concluded that factors that influenced the nasalance scores are children with RCLP have abnormal structures and functions of articulators, misarticulations,[11] voice disorders,[12,13] obstructions in the vocal tract,[14]snoring,[15,16] hearing impairment,[17,18] and phonological features.[8,9] Many studies on nasalance scores of children with RCLP compared with the non-cleft group, but no research on nasalance scores in children with RCLP using Thai SNAP Test. This research aims to study the nasalance scores and factors affecting nasalance scores in Thai children aged 4-7 assessed with Thai SNAP Test.

**Materials and methods**

***Subjects***

The subjects include group of children with RCLP and typically participants. The RCLP group is patients in the Speech and Language Clinic or who visit plastic surgeons at the Cleft Clinic. The control group is children without CLP who attended the Well-baby Clinic or came to Ramathibodi Hospital. Research participants are boys and girls, aged 4-7 years, with no age- and gender-matched between groups, and all 72 use the central Thai language. Children were excluded if they met one of the exclusion criteria: a child's parent refusing to participate in the research, children have any abnormalities (visual impairments, neurological conditions, syndromes), or on the day of data collection, they have upper respiratory tract infection (URI), e.g., cold and asthma, have uncooperative behavior.

***Data collection and analysis***

Data collection was provided at Ramathibodi Hospital from October 2018 to September 2019 after receiving the Certificate of Approval (Protocol Number 07-61-45) from a full board of the Human Research Ethics Unit, the Faculty of Medicine Ramathibodi Hospital.

Before starting nasometry each day, the nasometer (Nasometer II model 6450; Kay Elemetrics Corporation, Lincoln Park, NJ, USA) was calibrated according to the manufacturer's standard calibration procedure[19] in a quiet room. After receiving consent, the child's medical, health information, hearing ability, and language-speech development were taken. The screening test began with the oral-peripheral examination, language skills were evaluated by the language developmental screening test for diagnostic and treatment plans[20], and speech skills were assessed by asking a child to repeat four sentences from the Thai articulation screening test[21]. The child's visual and hearing abilities were observed while evaluating language and speech skills to confirm that all children have sufficient visual and hearing capabilities for nasometry.

The child was trained to produce all 25 items from Thai SNAP Test with actual loudness and speech rate. Nasalance scores were assessed by asking the child to repeat random speech stimuli after the instructor. If the child made a mistake or a long pause had to skip to another item and re-evaluate this item later. In case of the child was repeatedly misarticulated or unsure about speech sounds, visual and auditory cues were given to inform or correct each sound's production and to ensure that the child knew the right target sound.

Data were analyzed by a statistical software package Stata (version 16.0): the mean, SD, median, and minimum and maximum nasalance scores of each speech stimulus were calculated, then independently compared the mean nasalance scores between the control and the RCLP groups following this condition: normal distributions were examined by the t-test, and the non-normal distributions were calculated by Mann-Whitney U test. The mean differences in nasalance scores between the two groups were analyzed using the two-sample t-test with equal variances. The bootstrap confidence interval method was used to calculate the 95% Confident Interval (95% CI).

**Results**

Table 1 presents the age range of subjects in this study from 4-7 years, with a mean age of 5 years and 5 months. Both groups have more girls than boys. All non-cleft children in the control group had typical structures and functions of articulators and did not have speech-language and hearing problems that influenced nasalance scores. In contrast, children in the RCLP group have defective structures and functions of articulators due to the CLP, which were influential factors that affected the nasalance scores, including cleft lip and/ or palate, oronasal fistula (ONF), abnormal structure and function of velum, missing teeth/ malocclusion, obstructions in the vocal tract, and snoring. Moreover, children with CLP also led to speech-language and hearing problems, such as misarticulations, resonance disorders, nasal air emission (NAE), voice disorders, language-delayed development, and middle ear diseases.

Table 2 shows that most children with RCLP have hypernasality at least in one speech sound, and only 3 children with hyponasality that were detected while screening the speech skills. In addition, children with RCLP have nasal air emissions that can occur with hypernasality or compensatory errors and may cause higher nasalance scores. Nasal grimaces were found in 5 children with RCLP, which present excessive acoustic energy in the nasal cavity. The results of the articulation screening test showed that each child with RCLP had more than an error, finding that compensatory errors were as many as phonological disorders. The most common compensatory errors are nasalization, pharyngeal stops, and glottal fricatives, respectively. Children with RCLP frequently use substitutions for the target sound, such as backing, stopping, and gliding. In addition to substitution, also found distortion and omission. Children with RCLP who always use compensatory laryngeal adjustments to complete the velopharyngeal port led to voice disorders, another common speech problem in the RCLP group; this study found these problems characterized by hoarseness, breathiness, low pitch, or inconsistent loudness.

**Table 1** General data and oral-peripheral examination results.

| Variables | Control group (N=36) | RCLP group (N=36) |
|---|---|---|
| Age (years) | 5.5 (4.1, 6.8) | 5.5 (4.0, 7.0) |
| Gender | | |
| - Boy | 11 (30.56%) | 13 (36.11%) |
| - Girl | 25 (69.44%) | 23 (63.89%) |
| Cleft type | | |
| - Cleft palate | - | 13 (36.11%) |
| - Cleft lip and palate | - | 23 (63.89%) |
| Oronasal fistula (ONF) | - | 15 (41.67%) |
| Size of ONF | | |
| - Small (<2 mm) | - | 10 (27.78%) |
| - Medium (3-5 mm) | - | 4 (11.11%) |
| - Large (> 5 mm) | - | 1 (2.78%) |
| Site of ONF | | |
| - Junction soft/ hard palate | - | 9 (25%) |
| - Hard palate | - | 3 (8.33%) |
| - Lingual alveolar | - | 3 (8.33%) |
| Structure and function of velum | | |
| - Short velum | - | 34 (94.44%) |
| - Poor velar movement | - | 28 (77.78%) |
| Class III malocclusion | - | 27 (75%) |
| Missing upper and/or lower central incisors | 3 (8.33%) | 6 (16.67%) |
| Abnormal nose structure | - | 21 (58.33%) |
| - Cleft nose | - | 16 (44.44%) |
| - Cleft nose with nostril stenosis | - | 5 (13.89%) |
| Snoring problem | - | 12 (33.33%) |

Moreover, the language screening test showed that children with RCLP have language-delayed development with a limited vocabulary range, use simple sentence structures, or have less detail in the description. More than half of the children in the RCLP group have middle ear diseases, which the chronic middle ear diseases can lead to various types and degrees of hearing loss. This study found that some children with RCLP had unilateral moderately severe sensorineural hearing loss (the worse-hearing ear has hearing loss between 56 and 60 dB in speech frequencies), which may cause misarticulations in high-pressure oral consonants, especially fricatives and affricates by substitution, distortion, and omission, respectively. In this case, visual and auditory cues were

**Table 2** Numbers of speech-language and hearing problems assessed by the screening test.

| Variables | Control group (N=36) | RCLP group (N=36) |
|---|---|---|
| Resonance disorders | - | 33 (91.67%) |
| - Mild hypernasality | - | 13 (36.11%) |
| - Moderate hypernasality | - | 12 (33.33%) |
| - Severe hypernasality | - | 5 (13.89%) |
| - Hyponasality | - | 3 (8.33%) |
| *Nasal air emission (NAE)* | - | 16 (44.44%) |
| - Nasal rustle with hypernasality | - | 10 (27.78%) |
| - Visible NAE with hypernasality | - | 6 (16.67%) |
| *Nasal grimace* | - | 5 (13.89%) |
| Misarticulations | - | 33 (91.67%) |
| *Compensatory errors* | | |
| - Nasalization | - | 24 (66.67%) |
| - Pharyngeal stops | - | 17 (47.22%) |
| - Glottal fricatives | - | 14 (38.89%) |
| - Posterior nasal fricatives | - | 13 (36.11%) |
| - Pharyngeal fricatives | - | 13 (36.11%) |
| - Double glottal stops | - | 12 (33.33%) |
| - Mid-dorsum palatal stops | - | 9 (25%) |
| - Glottal stops | - | 8 (22.22%) |
| - Weak consonants | - | 5 (13.89%) |
| *Phonological errors* | | |
| - Distortion | - | 17 (47.22%) |
| - Omission | - | 11 (30.56%) |
| - Backing | - | 8 (22.22%) |
| - Stopping | - | 6 (16.67%) |
| - Gliding [j, w /l, r] | - | 6 (16.67%) |
| - Fronting | - | 5 (13.89%) |
| - Affrication | - | 5 (13.89%) |
| - Deaffricates | - | 5 (13.89%) |
| - Labialization | - | 4 (11.11%) |
| - Gliding of affricates [j, w/tç$^h$, tç] | - | 2 (5.56%) |
| - Gliding of fricatives [j, w/s, f] | - | 2 (5.56%) |
| - Vowel substitution | - | 2 (5.56%) |
| *Voice disorders* | - | 11 (30.56%) |
| *Delayed language development* | - | 4 (11.11%) |
| *Middle ear diseases and hearing impairment* | - | 21 (58.33%) |
| - Serous otitis media (SOM) | - | 13 (36.11%) |
| - SOM with unilateral mild to moderate conductive hearing loss (hearing loss between 30 and 55 dB in the speech frequencies in the worse-hearing ear) | - | 6 (16.67%) |
| - SOM with unilateral mild to moderately severe sensorineural hearing loss (hearing loss between 35 and 60 dB in the speech frequencies in the worse-hearing ear) | - | 2 (5.56%) |

used to prevent misunderstanding the target sounds, which may cause lower speech sound production accuracy.

***Nasalance scores of the control and the RCLP groups***

Nasalance scores from most speech stimuli were non-normal distributions. The normal distributions were found in data from nasal syllable repetition (/ma/ and /na/), prolonged /i/, and nasal sentences.

Table 3 showed that the nasalance scores of the RCLP group were significantly higher than the control group in all speech stimuli ($p$<0.05) with exception nasal syllables (/ma/, /ŋa/, /mi/, and /ŋi/), prolonged /m/, and nasal sentences, the scores of the RCLP were significantly lower than the control group ($p$ < 0.05). However, when data was assessed with nasal syllable repetition (/na/ and /ni/), the scores of the RCLP group were lower than those of the control group, with no significant difference ($p$≥0.05).

This study found that phonological features are another factor influencing nasalance scores, such as the mean nasalance scores of syllables consisting of a high-pressure oral consonant and vowel /a/ were lower than those with vowel /i/ by approximately 10%. For nasal syllables found, trends of the mean nasalance scores of syllables composing a nasal consonant and vowel /a/ were lower than those with /i/ by approximately 20%. The highest mean nasalance scores of both groups came from sustained /m/, whereas the lowest mean nasalance scores of each group were different; the lowest of the control group came from prolonged /s/ (0%), but the lowest of the RCLP group came from high-pressure oral syllable repetition, including /kʰa/ and /tɕʰa/ (20.06%).

Nasalance scores of the RCLP and the control groups are close when assessed with nasal syllable repetition (/na/ and /ni/), which may result from 3 RCLP children with hyponasality. Therefore, subgroup analysis was provided by excluding 3 children with hyponasality. Hence, the RCLP group had 33 children left and 36 children in the control group. The results of the subgroup analysis are shown in Table 4.

**Table 3** Nasalance scores (%) of the control and the RCLP groups.

| Subtest | Speech stimuli | Mean±SD | | Median (min, max) | | Mean difference (95% CI) |
|---|---|---|---|---|---|---|
| | | Control group (N=36) | RCLP group (N=36) | Control group (N=36) | RCLP group (N=36) | |
| **Subtest I:** Syllable repetition/ Prolonged sound | 1. /pʰa/ | 7.56±2.12 | 21.36 ± 16.44 | 7 (4, 13) | 16 (5, 55) | 13.81 (8.3-19.32) |
| | 2. /tʰa/ | 7.53±1.75 | 21.39 ± 15.44 | 7 (5, 12) | 13 (5, 61) | 13.86 (8.7-19.03) |
| | 3. /kʰa/ | 7.44±1.5 | 20.06 ± 14.37 | 8 (4, 10) | 15 (4, 55) | 12.61 (7.81-17.42) |
| | 4. /sa/ | 7.81±2.32 | 24.06 ± 17.11 | 7 (5, 14) | 22 (5, 60) | 16.25 (10.51 - 22) |
| | 5. /tɕʰa/ | 7.94±2.62 | 20.06±14.8 | 7.5 (5, 17) | 14.5 (4, 54) | 12.11 (7.11-17.11) |
| | 6. /pʰi/ | 19.94±7.19 | 35.25±22.44 | 21 (8, 38) | 25 (6, 76) | 15.31 (7.47-23.14) |
| | 7. /tʰi/ | 18.22±5.72 | 36.69±22.17 | 18 (8, 29) | 31 (9, 75) | 18.47 (10.86-26.08) |
| | 8. /kʰi/ | 22.11±6.19 | 36.08±21.58 | 22.5 (11, 35) | 31 (7, 81) | 13.97 (6.51-21.44) |
| | 9. /si/ | 16.58±5.71 | 36.53±23.21 | 16 (8, 29) | 27.5 (6, 79) | 19.94 (12-27.89) |
| | 10. /tɕʰi/ | 18.78±5.18 | 35.97±21.33 | 19 (12, 30) | 30.5 (9, 77) | 17.19 (9.9-24.49) |
| | 11. /ma/† | 58.92±8.27 | 54.14±10.44 | 60.5 (41, 75) | 53.5 (33, 79) | -4.78 (-9.21- -0.35) |
| | 12. /na/*† | 56.47±9.07 | 53.58±10.95 | 58 (32, 77) | 55 (31, 79) | -2.89 (-7.61-1.84) |
| | 13. /ŋa/ | 63.44±8.03 | 54.58±11.96 | 65 (42, 76) | 55 (27, 82) | -8.86 (-13.65 - -4.07) |
| | 14. /mi/ | 80.47±6.53 | 74.06±10.65 | 82 (67, 90) | 77 (48, 90) | -6.42 (-10.57- -2.26) |
| | 15. /ni/* | 76.22±7.69 | 71.58±11.95 | 76.5 (51, 86) | 72.5 (49, 89) | -4.64 (-9.36-0.08) |
| | 16. /ŋi/ | 78.92±6.9 | 72.97±11.04 | 82 (64, 88) | 75.5 (49, 92) | -5.94 (-10.27 - -1.62) |
| | 17. prolonged /a/ | 14.53±14.48 | 24.86±14.37 | 7 (4, 52) | 23.5 (5, 59) | 10.33 (3.55-17.12) |
| | 18. prolonged /i/ † | 20.97±7.79 | 47.39±22.44 | 21 (8, 35) | 45 (9, 89) | 26.42 (18.52-34.31) |
| | 19. prolonged /s/ | 0±0 | 26.44±35.50 | 0 (0, 0) | 0 (0, 96) | 26.44 (14.64-38.25) |
| | 20. prolonged /m/ | 93.58±2.55 | 91.25±6.28 | 94 (86, 97) | 93 (60, 97) | -2.33 (-4.59- -0.08) |
| **Subtest II:** Picture-cued sentences | 21. Bilabial plosives | 10.08±3.73 | 27.39±20.4 | 10.5 (4, 19) | 19 (5, 73) | 17.31 (10.41-24.2) |
| | 22. Lingual-alveolar plosives | 9.31±2.95 | 23.97±17.34 | 9 (5, 18) | 17.5 (6, 62) | 14.67 (8.82-20.51) |
| | 23. Velar plosives | 9.5 ± 3.01 | 22.47±15.48 | 10 (5, 19) | 16.5 (5, 61) | 12.97 (7.73-18.21) |
| | 24. Sibilant fricatives | 9.67 ± 3.14 | 26.08±17.17 | 10 (5, 18) | 25.5 (5, 64) | 16.42 (10.61-22.22) |
| | 25. Nasals † | 56.69 ± 6.31 | 51.89±10.04 | 56 (47, 76) | 50 (32, 72) | -4.81 (−8.75- -0.86) |

***Note:*** **not significant, † t-test*

**Table 4** Subgroup analysis of nasalance scores (%) of the control and the RCLP groups.

| Subtest | Speech stimuli | Mean±SD | | Median (min, max) | | Mean difference (95% CI) |
|---|---|---|---|---|---|---|
| | | Control group (N=36) | RCLP group (N=33) | Control group (N=36) | RCLP group (N=33) | |
| **Subtest I:** Syllable repetition/ Prolonged sound | 1. /pʰa/ | 7.56±2.12 | 21.42±16.91 | 7 (4, 13) | 15 (5, 55) | 13.87 (8.2, 19.54) |
| | 2. /tʰa/ | 7.53±1.75 | 21.36±15.79 | 7 (5, 12) | 12 (5, 61) | 13.84 (8.55, 19.12) |
| | 3. /kʰa/ | 7.44±1.5 | 20.24±14.79 | 8 (4, 10) | 14 (4, 55) | 12.8 (7.85, 17.74) |
| | 4. /sa/ | 7.8±2.32 | 23.18±16.93 | 7 (5, 14) | 20 (5, 60) | 15.38 (9.69, 21.06) |
| | 5. /tɕʰa/ | 7.94±2.62 | 20.55±15.32 | 7.5 (5, 17) | 15 (4, 54) | 12.6 (7.43, 17.78) |
| | 6. /pʰi/ | 19.94±7.19 | 36.42±22.85 | 21 (8, 38) | 26 (6, 76) | 16.48 (8.48, 24.48) |
| | 7. /tʰi/ | 18.22±5.72 | 38.03±22.45 | 18 (8, 29) | 38 (9, 75) | 19.81 (12.08, 27.53) |
| | 8. /kʰi/ | 22.11±6.19 | 37.27±21.91 | 22.5 (11, 35) | 36 (8, 81) | 15.16 (7.57, 22.76) |
| | 9. /si/ | 16.58±5.71 | 36.85±23.87 | 16 (8, 29) | 27 (6, 79) | 20.27 (12.09, 28.44) |
| | 10. /tɕʰi/ | 18.78±5.18 | 36.7±21.93 | 19 (12, 30) | 26 (9, 77) | 17.92 (10.41, 25.43) |
| | 11. /ma/† | 58.92±8.27 | 55.21±10.18 | 60.5 (41, 75) | 55 (33, 79) | -3.7 (-8.15-0.74) |
| | 12. /na/*† | 56.47±9.07 | 54.64±10.65 | 58 (32, 77) | 56 (31, 79) | -1.84 (-6.58-2.91) |
| | 13. /ŋa/ | 63.44±8.03 | 55.64±11.79 | 65 (42, 76) | 56 (27, 82) | -7.81 (-12.62- -3) |
| | 14. /mi/ | 80.47±6.53 | 74.88±10.26 | 82 (67, 90) | 78 (48, 90) | -5.59 (-9.69- -1.5) |
| | 15. /ni/* | 76.22±7.69 | 72.82±11.47 | 76.5 (51, 86) | 74 (49, 89) | -3.4 (-8.06-1.25) |
| | 16. /ŋi/ | 78.92±6.9 | 73.67±10.94 | 82 (64, 88) | 76 (49, 92) | -5.25 (-9.61- -0.89) |
| | 17. prolonged /a/ | 14.53±14.48 | 25.55±14.68 | 7 (4, 52) | 26 (5, 59) | 11.02 (4-18.03) |
| | 18. prolonged /i/ † | 20.97±7.79 | 48.61±22.67 | 21 (8, 35) | 46 (9, 89) | 27.63 (19.62-35.64) |
| | 19. prolonged /s/ | 0±0 | 28.3±36.46 | 0 (0, 0) | 0 (0, 96) | 28.3 (16.18-40.42) |
| | 20. prolonged /m/ | 93.58±2.55 | 91.24±6.52 | 94 (86, 97) | 93 (60, 97) | -2.34 (-4.68-0) |
| **Subtest II:** Picture-cued sentences | 21. Bilabial plosives | 10.08±3.73 | 28.45±20.87 | 10.5 (4, 19) | 20 (6, 73) | 18.37 (11.31-25.43) |
| | 22. Lingual-alveolar plosives | 9.31±2.95 | 24.85±17.72 | 9 (5, 18) | 18 (6, 62) | 15.54 (9.56, 21.52) |
| | 23. Velar plosives | 9.5±3.01 | 22.76±15.8 | 10 (5, 19) | 15 (6, 61) | 13.26 (7.9, 18.61) |
| | 24. Sibilant fricatives | 9.67±3.14 | 26.45±17.37 | 10 (5, 18) | 26 (5, 64) | 16.79 (10.91, 22.66) |
| | 25. Nasals † | 56.69±6.31 | 52.85±9.91 | 56 (47, 76) | 51 (32, 72) | -3.85 (-7.8-0.11) |

***Note:*** **not significant, † t-test*

## Discussion

This study aims to apply the Thai SNAP Test to assess nasalance scores in Thai children with RCLP aged 4-7 years. Due to the limited sample size (36 children per group), therefore could not analyze nasalance scores separately to gender or age range. However, trends of nasalance scores agreed with previous studies that reported gender and age are not influential factors for nasalance scores in children aged 4 to 7. Because at this age, all children had similar shapes and sizes of the vocal tract, resulting in similar mean nasalance scores and could represent the scores of the entire group.[2,4,5]

Nasalance scores of the RCLP group were significantly higher than the control group when evaluated with high-pressure oral speech stimuli ($p$<0.05). In contrast, the nasalance scores of the RCLP group were lower than the control group when using nasal speech stimuli, which agreed with several studies.[7-10] Moreover, this study agreed with the previous research that informed factors that influenced nasalance scores, including abnormal structures and functions of articulators, misarticulations,[11] voice disorders,[12,13] obstructions in the vocal tract,[14] snoring,[15,16] hearing impairments,[17,18] and phonological features.[8,9] Each factor affects the nasalance scores in different aspects, as follows.

Higher nasalance scores than the control group can describe by the RCLP group having defective structures and functions of articulators resulting from CLP including ONF, and VPI, which can cause various types of misarticulations and hearing impairments.[17,18] This study found that 10 children with RCLP (27.78%) have a small penetrating ONF and 12 of 15 children have ONF at the anterior palate region, which this ONF's size and the site usually impact high-pressure oral consonants because the ONF locates at the same area as the placement of articulation of high-pressure oral consonants.[22-24] When a lifted tongue opposes an ONF, the tongue pushes acoustic energy into the nasal cavity, causing nasal resonance. Moreover, this study found 44.44% of the RCLP group have some energy rub against the edge of the ONF, creating nasal emission that disturbs speech and can cause increased nasalance scores.[1,12,22]

The VPI caused by short velum or poor velar movement mainly affects high vowels or voiced oral consonants because while producing these sounds, acoustic energy leaks through a velopharyngeal gap and then generates nasal resonance, resulting in increased nasalance scores. The acoustic energy leakage caused 5 children with RCLP (13.89%) to tense facial or nasal muscles to close the velopharyngeal gap or diminish excessive nasal resonance, resulting in nasal or facial grimaces.[12]

This study found that 33 of 36 children (91.67%) in the RCLP group have misarticulations, compensatory and phonological errors equally. Children with RCLP have compensatory errors with nasal rustle and hypernasality, such as mid-dorsum palatal stops, posterior nasal fricatives, and pharyngeal fricatives may increase nasalance scores.[12] The frequent pattern of phonological errors is substitutions because children with RCLP have atypical articulators. Children cannot produce the target sound correctly and need to substitute the sound they can produce for the target sounds. Substitutions affect the validity of nasalance scores because the scores may come from a substituted sound, not a target sound, such as a child substitutes a nasal consonant for an oral consonant.[1,12] These findings conform to Nandurkar who reported that all children with RCLP misarticulated at least one position in a pressure-sensitive word, the most common was substitution (19.44%) also found that nasalance scores of the RCLP group were higher than the non-cleft group.[8]

CLP affects the Eustachian tube's functions and causes middle ear disease. In this study, most children with RCLP have a history of serous otitis media (SOM), or SOM remains, and 8 of 36 children with RCLP (22.22%) have SOM with unilateral hearing impairments, which levels of hearing loss between 30 and 60 dB in speech frequencies.[25] Hearing-impaired children may have higher nasalance scores because children with hearing issues have a slower speech rate than those with normal hearing, causing incomplete velopharyngeal closure, resulting in the acoustic energy leak through the velopharyngeal gap to the nasal cavity, creating nasal resonance and causing hypernasality.[18] Moreover, hearing impairment causes misarticulations, especially in voiceless consonants. Because these consonants are low-intensity and hard for hearing-impaired children to produce correctly. Misarticulations, such as substitutions, or distortions due to hearing loss may be another factor that affects the validity of the nasalance scores.[17]

The significantly lower nasalance scores of the RCLP group, when assessed with nasal speech stimuli, are consistent with a study by Abou-Elsaad *et al*.[7] reported that nasalance scores of the RCLP group were significantly lower than those of the control group when assessed with nasal syllable repetition (/ma/, /na/, /mi/, and /ni/) from the Arabic SNAP Test. This study found that hyponasal speech in 3 RCLP children might result from an obstruction in the vocal tract and voice disorders.

This study found that the obstruction in the vocal tract, including the cleft nose with or without nostril stenosis and hypertrophic structures with snoring that occludes the energy from exiting through the nasal cavity,[14-16] resulting in hyponasality.[1] Furthermore, this study agreed with Sadjadi *et al*. reported that having voice disorders cause decreased acoustic energy and lower nasalance scores than children without voice disturbance.[26] Voice disorders occur in children with mild VPI who used to strain vocal cords to close the symptomatic ONF or a small velopharyngeal gap for having sufficient vocal loudness.[12,13,27] The present study found that 30.56% of children with RCLP had voice disorders with low pitch or soft voice, resulting in the RCLP having lower nasalance scores than the control group.

Only two nasal syllable repetitions (/na/ and /ni/), which nasalance scores of the RCLP group were lower than those of the control group, but not a significant difference ($p \geq 0.05$). These results can be described by the range of nasalance scores of the two groups are almost no difference. A large range of nasalance scores means low validity.[1] Vary nasalance scores may result from most children with RCLP having misarticulations in /n/. Because the children could not raise the tip of the tongue to precisely reach the alveolar ridge, an /n/ sound was distorted or substituted [ŋ/n], decreasing the validity of nasalance scores because the scores did not come from a target sound. Moreover, thirteen children with RCLP had mild hypernasality, which challenged a nasometer to identify speech resonance problems and cause nasalance scores close to the control group that comply with Dalston *et al*. which informed that a nasometer could accurately determine resonance disorders in patients with more than mild hypernasality.[28,29] The results of this study correlate with the previous studies, suggesting nasal speech stimuli are proper for measuring hyponasality, not hypernasality. Because nasal consonants mainly resonate in the nasal cavity. It is difficult for a nasometer to differentiate between normal nasal resonance and hypernasality.[1,3,9]

Comparing nasalance scores within the same group revealed that the impact factors were the phonological features of consonants and vowels used in each stimulus. This study found that nasalance scores from nasal speech stimuli were significantly higher than high-pressure oral speech stimuli; for example, the scores from prolonged /m/ were the highest because the nasal resonance mainly occurred. [2,5,7]

In contrast, the lowest nasalance scores (0%) were found in the control group when sustained /s/. Because /s/ is an oral voiceless consonant, only oral resonance occurs; children in the control group could close the velopharyngeal port tightly, with no energy entering the nasal cavity.[1] However, in 44.44% of the RCLP group, the mean nasalance scores were higher than 0% because children may have nasal resonance due to nasal emission or have compensatory errors with a nasal rustle while prolonging /s/.[12] These results correspond to Watterson *et al*. which indicated that different numbers of nasal phonemes impact the nasalance scores; a speech stimulus with more nasal phonemes results in higher nasalance scores than with fewer or without nasals.[9] Because of the assimilation phenomenon of nasal consonants, a nasal consonant assimilates to an adjacent vowel, causing a nasalized vowel, which was accepted as normal nasalization.[24,30,31] Furthermore, phonological features of vowels also influenced nasalance scores. In high vowels, an elevated tongue causes a narrower oral cavity and rising intraoral pressure that pushes acoustic energy to the nasal cavity, resulting in oronasal resonance generating higher nasalance scores. In contrast, low vowels, a lower tongue with a wide mouth, decreasing intraoral pressure, and the energy cannot flow into the nasal cavity. Thus, only oral resonance occurs, causing lower nasalance scores.[1,2]

**Conclusion**

For further studies, this research recommends assessing screening tests with the instruments, including screening hearing levels using audiometry test and assessing the velopharyngeal port by direct measurements such as nasopharyngoscopy or multi-view videofluoroscopy, which present the degree of hearing and illustrate the size of the velopharyngeal gap, and the types of VPI may reveal the correlation between these factors and the nasalance scores. The present study found that ONF is another influential factor with the limited number of subjects that could not specify that ONF or VPI impacted the nasalance scores. Further study should increase the sample size and group children in the RCLP group into two groups, including RCLP children with ONF and RCLP children without ONF, then compare the nasalance scores of the two RCLP groups with the control group may identify the main factor affecting the nasalance scores. Accents and dialects also impact nasalance scores therefore, researchers should evaluate nasalance scores in Thai children who use different regional dialects. Moreover, researchers should study normative nasalance scores of Thai SNAP Test with a substantial sample size to represent each gender and age range and show the impact of gender and age on nasalance scores can be used as the reference data for measuring speech resonance disorders.

In conclusion, this study revealed the trends in nasalance scores, which suggested that Thai SNAP Test could identify speech resonance disorders in Thai children aged 4-7 years. However, for diagnosing or evaluating the progression of treatments, the SLP or evaluator should consider factors that affect the nasalance scores, as mentioned above. For precise diagnosing and assessing the progression of the therapy should apply nasalance scores together with other results, including perceptual nasality ratings evaluated by experienced SLPs in cleft palate speech, which is the gold standard, integrated with the results from various methods or instruments.

**Conflict of interest:**

The authors declare no conflict of interest.

**Ethics approval:**

This research was approved on September 17, 2018, and expired on September 16, 2019, with COA. No. MURA2018/ 532.

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**References**

[1] Kummer AW. Nasometry. In: Kummer AW, editor. Cleft Palate and craniofacial anomalies: Effects on speech and resonance. 3rd ed. New York: Cengage Learning; 2013; 400- 34.

[2] MacKay IR, Kummer AW. The MacKay–Kummer SNAP test-R simplified nasometric assessment procedures [Revised 2005]. Kay Elemetrics Corp, Instrument Manual Nasometer Model 6450. 2005; 115-24.

[3] Ünal-Logacev Ö, Kummer AW, Çetin C, Topbaş S. Nasometric evaluation of resonance disorders: A norm study In Turkish. Int J Pediatr Otorhinolaryngol. 2020; 131: 109888.

[4] Sadeghi S, Derakhshandeh F, Abdali H, Rezaei P. Nasalance scores for normal Persian-speaking girls. Dis Diagn. 2021; 10(1): 13-8.

[5] Liadprathom K. The construction and development of Thai simplified nasometric assessment procedures (Thai SNAP Test) for children aged 4 to 6 years (MA Thesis in Communication Disorders). Bangkok: Mahidol University; 2017.

[6] Mukngoen S. Articulatory characteristics of school children aged three to eight years in Phya-Thai area (MA Thesis in Communication Disorders). Bangkok: Mahidol University; 1980.

[7] Abou-Elsaad T, Afsah O, Baz H, Mansy A. Evaluating the diagnostic accuracy of Arabic SNAP test for children with hypernasality. Int J Pediatr Otorhinolaryngol. 2016; 85: 99-102.

[8] Wahab NA, Jamaluddin J, Vandort S, Samsudin AR. Nasalance scores of Malay (Kelantan dialect) in children with and without palatal cleft. Arch Orofac Sci. 2013; 8(1): 27-33.

[9] Watterson T, Hinton J, McFarlane S. Novel stimuli for obtaining nasalance measures from young children. Cleft Palate Craniofac J. 1996; 33(1): 67-73.

[10] Van Lierde K, De Bodt M, Van Borsel J, Wuyts F, Van Cauwenberge P. Effect of cleft type on overall speech intelligibility and resonance. Folia Phoniatr Logop. 2002; 54(3): 158-68.

[11] Nandurkar A. Nasalance measures in Marathi consonant-vowel-consonant syllables with pressure consonants produced by children with and without cleft lip and palate. Cleft Palate Craniofac J. 2002; 39(1): 59-65.

[12] Kummer AW. Resonance disorders and velopharyngeal dysfunction (VPD). In: Kummer AW, editor. Cleft Palate and craniofacial anomalies: Effects on speech and resonance. 3$^{rd}$ ed. New York: Cengage Learning; 2013. p. 182-224.

[13] Sally J. Peterson-Falzone, Mary A. Hardin-Jones, Michael P. Karnell. Cleft palate speech. 4$^{th}$ ed. St. Louis: Mosby Elsevier; 2010; 221-48.

[14] Nieminen P, Löppönen H, Väyrynen M, Tervonen A, Tolonen U. Nasalance scores in snoring children with

obstructive symptoms. Int J Pediatr Otorhinolaryngol. 2000 Jan 30; 52(1): 53-60.

[15] Georgalas C. The role of the nose in snoring and obstructive sleep apnoea: an update. Eur Arch Otorhinolaryngol. 2011; 268(9): 1365-73.

[16] Kummer AW, Billmire DA, Myer CM, 3rd. Hypertrophic tonsils: the effect on resonance and velopharyngeal closure. Plast Reconstr Surg. 1993; 91(4): 608-11.

[17] Fletcher SG, Daly DA. Nasalance in utterances of hearing-impaired speakers. J Commun Disord. 1976; 9(1): 63-73.

[18] Fletcher SG, Mahfuzh F, Hendarmin H. Nasalance in the speech of children with normal hearing and children with hearing loss. Am J Speech Lang Pathol. 1999; 8(3): 241-8.

[19] Kay Elemetrics Corp. Maintenance and calibration In: Kay Elemetrics Corp, Instrument Manual Nasometer Model 6450. New Jersey: Kay Elemetrics Corp; 2010; 4.

[20] Preeya Lorwattanapongsa. the screening and stimulating language and speech development. In: Benjamas Prathanee, editor. Language, Speech, and Hearing of Cleft Lip and Palate: Classification. Khon Kaen: Klungnana Vitthaya Press; 2008; 102-20.

[21] Benjamas Prathanee. Assessment and speech therapy for articulation problems in children with cleft lip and palate. In: Benjamas Prathanee, Editor. Cleft lip and cleft palate. Speech problems and multidisciplinary treatment Volume 2. Khon Kaen: KKU printing house; 2014; 393-442.

[22] Kummer AW, Curtis C, Wiggs M, Lee L, Strife JL. Comparison of velopharyngeal gap size in patients with hypernasality, hypernasality and nasal emission, or nasal turbulence (rustle) as the primary speech characteristic. Cleft Palate Craniofac J. 1992; 29(2): 152-6.

[23] Agrawal K. Cleft palate repair and variations. Indian J Plast Surg. 2009; 42: 102-9.

[24] Kanchana Naksakul. Thai consonant phonemes. The Thai language sound system. 6th edition Bangkok: Chulalongkorn University; 2008. p. 117-28.

[25] Stool SE. Diseases of the ear in children with cleft palate and craniofacial anomalies. In: Berkowitz S, editor. Cleft Lip and Palate. Berlin, Heidelberg: Springer Berlin Heidelberg; 2006; 355-62.

[26] Sadjadi V, Ghorbani A, Torabinezhad F, Amiri Y, Keyhani MR. The effect of vocal loudness on nasalance of vowels in Persian adults. Iran Rehabil J. 2010; 8(2): 31-5.

[27] Robison JG, Otteson TD. Prevalence of Hoarseness in the Cleft Palate Population. Arch Otolaryngol Head Neck Surg. 2011; 137(1): 74–77.

[28] Pegoraro-Krook MI, de Cássia Rillo Dutka J, de Castro Marino VC, Silva L. Correlation between nasalance and nasality in children with hypernasality. Revista CEFAC. 2014; 16(6): 1936-43.

[29] Dalston RM, Warren DW, Dalston ET. Use of nasometry as a diagnostic tool for identifying patients with velopharyngeal impairment. Cleft Palate Craniofac J. 1991; 28(2): 184-9.

[30] Kuehn DP, Moller KT. Speech and language issues in the cleft palate population: The state of the art. Cleft Palate Craniofac J. 2000; 37(4): 1-35.

[31] Kanchana Naksakul. Thai vowel phonemes. The Thai language sound system. 6th edition Bangkok: Chulalongkorn University; 2008; 79-115.

**Appendix 1:** Nasalance scores of the control group

| Code | Syllable repetition | | | | | | | | | | | | | | | | Prolonged sound | | | | Picture-cued sentences | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | p$^{h}$a | t$^{h}$a | k$^{h}$a | sa | tç$^{h}$a | p$^{h}$i | t$^{h}$i | k$^{h}$i | si | tç$^{h}$i | ma | na | ŋa | mi | ni | ŋi | a | i | s | m | Bilabials | Alveolar plosives | Velars | Alveolar fricatives | Nasals |
| C-01 | 7 | 9 | 8 | 8 | 8 | 12 | 12 | 16 | 11 | 15 | 56 | 57 | 64 | 75 | 68 | 73 | 37 | 10 | 0 | 96 | 6 | 9 | 8 | 10 | 55 |
| C-02 | 4 | 5 | 4 | 5 | 6 | 19 | 19 | 14 | 17 | 19 | 64 | 60 | 76 | 86 | 84 | 82 | 4 | 27 | 0 | 97 | 7 | 7 | 6 | 6 | 54 |
| C-03 | 12 | 11 | 10 | 10 | 12 | 26 | 23 | 28 | 18 | 17 | 61 | 65 | 73 | 86 | 81 | 83 | 9 | 15 | 0 | 94 | 11 | 7 | 10 | 10 | 67 |
| C-04 | 6 | 6 | 6 | 5 | 5 | 8 | 9 | 14 | 10 | 13 | 51 | 48 | 52 | 70 | 66 | 74 | 7 | 13 | 0 | 95 | 5 | 6 | 6 | 5 | 48 |
| C-05 | 12 | 8 | 9 | 8 | 9 | 17 | 18 | 22 | 14 | 14 | 62 | 59 | 68 | 81 | 74 | 79 | 7 | 8 | 0 | 92 | 9 | 11 | 11 | 10 | 53 |
| C-06 | 7 | 7 | 8 | 6 | 5 | 8 | 8 | 14 | 8 | 13 | 49 | 47 | 42 | 87 | 83 | 78 | 8 | 8 | 0 | 94 | 4 | 5 | 7 | 5 | 53 |
| C-07 | 13 | 8 | 8 | 13 | 9 | 25 | 16 | 26 | 27 | 19 | 67 | 63 | 65 | 69 | 65 | 74 | 6 | 29 | 0 | 96 | 11 | 13 | 11 | 10 | 64 |
| C-08 | 6 | 6 | 6 | 5 | 6 | 17 | 14 | 15 | 8 | 13 | 45 | 32 | 52 | 81 | 69 | 66 | 12 | 13 | 0 | 91 | 5 | 6 | 5 | 7 | 48 |
| C-09 | 6 | 7 | 10 | 7 | 5 | 13 | 11 | 11 | 8 | 12 | 63 | 66 | 65 | 80 | 75 | 81 | 9 | 11 | 0 | 95 | 7 | 7 | 10 | 9 | 53 |
| C-10 | 5 | 6 | 7 | 6 | 7 | 8 | 13 | 18 | 11 | 12 | 52 | 53 | 52 | 73 | 65 | 67 | 5 | 17 | 0 | 92 | 6 | 9 | 7 | 6 | 50 |
| C-11 | 8 | 8 | 8 | 7 | 7 | 24 | 18 | 32 | 15 | 22 | 42 | 43 | 56 | 76 | 66 | 72 | 7 | 22 | 0 | 94 | 8 | 10 | 8 | 10 | 53 |
| C-12 | 5 | 7 | 6 | 5 | 5 | 10 | 11 | 15 | 15 | 14 | 56 | 52 | 65 | 90 | 83 | 83 | 39 | 23 | 0 | 96 | 6 | 7 | 7 | 7 | 56 |
| C-13 | 9 | 8 | 8 | 10 | 9 | 21 | 19 | 22 | 20 | 21 | 54 | 55 | 62 | 71 | 75 | 69 | 20 | 19 | 0 | 90 | 11 | 8 | 11 | 10 | 52 |
| C-14 | 11 | 11 | 10 | 12 | 11 | 33 | 18 | 17 | 16 | 23 | 60 | 60 | 67 | 82 | 77 | 84 | 9 | 13 | 0 | 93 | 13 | 13 | 11 | 11 | 67 |
| C-15 | 8 | 9 | 8 | 9 | 10 | 12 | 15 | 15 | 16 | 16 | 54 | 49 | 68 | 83 | 76 | 69 | 7 | 17 | 0 | 95 | 13 | 11 | 11 | 12 | 58 |
| C-16 | 7 | 7 | 7 | 6 | 7 | 21 | 17 | 16 | 8 | 13 | 54 | 46 | 50 | 67 | 70 | 64 | 7 | 16 | 0 | 90 | 8 | 7 | 6 | 6 | 48 |
| C-17 | 6 | 7 | 8 | 7 | 6 | 17 | 19 | 26 | 17 | 18 | 43 | 59 | 59 | 86 | 81 | 83 | 5 | 18 | 0 | 91 | 8 | 6 | 8 | 8 | 51 |
| C-18 | 10 | 8 | 8 | 8 | 8 | 18 | 27 | 28 | 12 | 21 | 69 | 67 | 64 | 75 | 79 | 82 | 42 | 33 | 0 | 93 | 16 | 10 | 10 | 11 | 61 |
| C-19 | 7 | 7 | 6 | 9 | 7 | 22 | 21 | 29 | 21 | 24 | 66 | 59 | 68 | 89 | 83 | 84 | 43 | 26 | 0 | 96 | 15 | 15 | 16 | 18 | 76 |
| C-20 | 8 | 6 | 6 | 7 | 7 | 14 | 12 | 25 | 15 | 21 | 59 | 48 | 64 | 76 | 71 | 82 | 6 | 22 | 0 | 96 | 6 | 9 | 6 | 6 | 56 |
| C-21 | 7 | 7 | 8 | 6 | 6 | 23 | 15 | 28 | 13 | 23 | 65 | 62 | 67 | 81 | 80 | 84 | 5 | 15 | 0 | 92 | 11 | 10 | 10 | 8 | 58 |
| C-22 | 7 | 8 | 7 | 9 | 8 | 19 | 15 | 23 | 17 | 14 | 75 | 77 | 75 | 88 | 85 | 87 | 8 | 25 | 0 | 97 | 10 | 8 | 10 | 10 | 62 |
| C-23 | 8 | 7 | 6 | 6 | 7 | 12 | 14 | 17 | 11 | 12 | 50 | 53 | 62 | 85 | 75 | 80 | 7 | 12 | 0 | 93 | 7 | 8 | 10 | 8 | 55 |
| C-24 | 8 | 9 | 8 | 9 | 10 | 21 | 25 | 28 | 20 | 21 | 67 | 62 | 65 | 85 | 84 | 87 | 7 | 15 | 0 | 89 | 15 | 11 | 11 | 10 | 56 |
| C-25 | 7 | 7 | 7 | 6 | 5 | 28 | 26 | 25 | 20 | 23 | 67 | 56 | 65 | 85 | 79 | 84 | 7 | 20 | 0 | 94 | 17 | 9 | 8 | 8 | 55 |
| C-26 | 11 | 12 | 9 | 14 | 17 | 30 | 22 | 29 | 21 | 30 | 65 | 56 | 66 | 83 | 76 | 85 | 35 | 30 | 0 | 95 | 15 | 18 | 14 | 13 | 60 |
| C-27 | 9 | 11 | 10 | 11 | 11 | 23 | 25 | 26 | 26 | 25 | 68 | 67 | 71 | 84 | 81 | 80 | 7 | 24 | 0 | 96 | 19 | 15 | 19 | 17 | 62 |
| C-28 | 7 | 8 | 8 | 9 | 12 | 25 | 22 | 26 | 19 | 19 | 64 | 53 | 64 | 70 | 72 | 82 | 8 | 32 | 0 | 86 | 11 | 7 | 7 | 10 | 47 |
| C-29 | 7 | 7 | 9 | 8 | 9 | 28 | 13 | 21 | 14 | 21 | 66 | 61 | 76 | 86 | 83 | 88 | 52 | 26 | 0 | 92 | 10 | 10 | 10 | 10 | 54 |
| C-30 | 6 | 7 | 6 | 7 | 8 | 19 | 20 | 23 | 16 | 16 | 59 | 59 | 66 | 85 | 84 | 82 | 6 | 24 | 0 | 93 | 11 | 8 | 10 | 10 | 60 |
| C-31 | 6 | 5 | 6 | 7 | 6 | 22 | 22 | 24 | 22 | 26 | 41 | 37 | 47 | 68 | 51 | 64 | 18 | 30 | 0 | 90 | 11 | 7 | 8 | 13 | 49 |
| C-32 | 8 | 9 | 9 | 11 | 10 | 27 | 29 | 35 | 29 | 27 | 64 | 72 | 70 | 82 | 86 | 85 | 7 | 35 | 0 | 94 | 14 | 14 | 14 | 15 | 64 |
| C-33 | 6 | 7 | 7 | 7 | 8 | 38 | 27 | 32 | 28 | 25 | 57 | 57 | 69 | 87 | 81 | 87 | 7 | 31 | 0 | 96 | 11 | 10 | 13 | 15 | 58 |
| C-34 | 6 | 5 | 5 | 5 | 5 | 21 | 13 | 18 | 14 | 12 | 63 | 60 | 69 | 84 | 86 | 83 | 49 | 17 | 0 | 94 | 7 | 8 | 8 | 7 | 56 |
| C-35 | 6 | 5 | 6 | 7 | 10 | 24 | 29 | 21 | 24 | 27 | 63 | 60 | 64 | 82 | 75 | 77 | 4 | 34 | 0 | 96 | 11 | 9 | 7 | 8 | 62 |
| C-36 | 6 | 6 | 6 | 6 | 5 | 13 | 19 | 17 | 16 | 15 | 60 | 53 | 56 | 79 | 75 | 77 | 7 | 25 | 0 | 96 | 8 | 7 | 8 | 9 | 60 |

**Appendix 2:** Nasalance scores of the RCLP group

| Code | Syllable repetition | | | | | | | | | | | | | | | | Prolonged sound | | | | Picture-cued sentences | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | p$^h$a | t$^h$a | k$^h$a | sa | tç$^h$a | p$^h$i | t$^h$i | k$^h$i | si | tç$^h$i | ma | na | ŋa | mi | ni | ŋi | a | i | s | m | Bilabials | Alveolar plosives | Velars | Alveolar fricatives | Nasals |
| R-01 | 11 | 28 | 16 | 20 | 11 | 16 | 26 | 25 | 39 | 19 | 53 | 66 | 68 | 75 | 74 | 75 | 44 | 44 | 64 | 93 | 10 | 14 | 18 | 26 | 48 |
| R-02 | 11 | 12 | 9 | 11 | 8 | 13 | 15 | 11 | 15 | 11 | 45 | 44 | 55 | 61 | 59 | 66 | 26 | 33 | 0 | 89 | 13 | 17 | 9 | 15 | 45 |
| R-03 | 41 | 18 | 19 | 32 | 37 | 51 | 39 | 61 | 37 | 44 | 44 | 58 | 53 | 53 | 61 | 58 | 17 | 37 | 0 | 91 | 44 | 39 | 29 | 31 | 47 |
| R-04 | 7 | 8 | 5 | 5 | 6 | 13 | 16 | 13 | 14 | 13 | 33 | 42 | 37 | 67 | 61 | 62 | 5 | 25 | 0 | 94 | 8 | 12 | 7 | 7 | 47 |
| R-05 | 9 | 8 | 11 | 8 | 10 | 20 | 26 | 26 | 23 | 26 | 72 | 52 | 66 | 67 | 70 | 69 | 5 | 35 | 0 | 93 | 14 | 13 | 11 | 12 | 57 |
| R-06 | 6 | 11 | 6 | 7 | 6 | 13 | 15 | 15 | 16 | 14 | 53 | 46 | 47 | 72 | 70 | 64 | 30 | 14 | 0 | 93 | 10 | 20 | 11 | 9 | 44 |
| R-07 | 6 | 6 | 6 | 7 | 6 | 24 | 16 | 16 | 21 | 17 | 62 | 59 | 65 | 81 | 82 | 83 | 5 | 38 | 0 | 96 | 7 | 9 | 9 | 11 | 56 |
| R-08 | 40 | 43 | 38 | 43 | 34 | 62 | 57 | 52 | 60 | 47 | 56 | 57 | 55 | 67 | 69 | 66 | 41 | 70 | 92 | 91 | 55 | 46 | 42 | 44 | 52 |
| R-09 | 24 | 36 | 11 | 55 | 49 | 61 | 75 | 53 | 73 | 77 | 58 | 56 | 51 | 87 | 88 | 86 | 27 | 65 | 71 | 96 | 41 | 46 | 19 | 45 | 55 |
| R-10 | 33 | 35 | 29 | 46 | 11 | 22 | 21 | 30 | 52 | 35 | 46 | 39 | 36 | 57 | 51 | 58 | 19 | 48 | 18 | 89 | 18 | 13 | 21 | 40 | 41 |
| R-11 | 42 | 33 | 26 | 27 | 29 | 41 | 41 | 39 | 32 | 39 | 37 | 31 | 27 | 66 | 55 | 53 | 17 | 47 | 0 | 88 | 36 | 29 | 30 | 25 | 40 |
| R-12 | 21 | 22 | 17 | 44 | 21 | 36 | 36 | 32 | 28 | 36 | 44 | 51 | 51 | 58 | 54 | 60 | 25 | 39 | 0 | 90 | 24 | 24 | 32 | 21 | 38 |
| R-13 | 6 | 14 | 7 | 6 | 8 | 20 | 14 | 16 | 12 | 18 | 41 | 34 | 36 | 61 | 51 | 55 | 21 | 38 | 0 | 89 | 13 | 13 | 11 | 9 | 49 |
| R-14 | 8 | 8 | 11 | 7 | 6 | 29 | 26 | 23 | 11 | 26 | 52 | 44 | 45 | 78 | 61 | 72 | 11 | 41 | 18 | 91 | 7 | 6 | 7 | 5 | 37 |
| R-15 | 7 | 6 | 5 | 6 | 7 | 6 | 14 | 12 | 21 | 19 | 59 | 57 | 70 | 84 | 78 | 73 | 12 | 18 | 19 | 93 | 6 | 9 | 6 | 7 | 63 |
| R-16 | 53 | 61 | 46 | 60 | 50 | 76 | 70 | 81 | 72 | 74 | 79 | 79 | 82 | 81 | 83 | 84 | 59 | 80 | 96 | 95 | 73 | 62 | 61 | 64 | 72 |
| R-17 | 5 | 10 | 18 | 8 | 7 | 11 | 48 | 45 | 6 | 18 | 51 | 62 | 61 | 69 | 74 | 76 | 9 | 63 | 0 | 91 | 6 | 8 | 15 | 9 | 48 |
| R-18 | 17 | 23 | 25 | 27 | 29 | 33 | 44 | 46 | 45 | 42 | 58 | 60 | 50 | 80 | 71 | 78 | 28 | 50 | 0 | 91 | 29 | 13 | 15 | 30 | 57 |
| R-19 | 55 | 53 | 55 | 52 | 54 | 74 | 74 | 74 | 76 | 70 | 69 | 66 | 57 | 82 | 79 | 86 | 49 | 83 | 68 | 95 | 61 | 59 | 55 | 54 | 67 |
| R-20 | 6 | 11 | 12 | 9 | 8 | 26 | 13 | 25 | 21 | 23 | 49 | 47 | 53 | 81 | 81 | 78 | 21 | 30 | 0 | 87 | 12 | 6 | 9 | 7 | 40 |
| R-21 | 5 | 5 | 7 | 5 | 5 | 16 | 16 | 21 | 19 | 22 | 55 | 51 | 59 | 83 | 86 | 83 | 5 | 46 | 0 | 94 | 9 | 6 | 8 | 8 | 51 |
| R-22 | 7 | 8 | 7 | 8 | 10 | 16 | 13 | 18 | 14 | 15 | 60 | 63 | 64 | 76 | 76 | 73 | 8 | 19 | 0 | 94 | 13 | 7 | 9 | 12 | 51 |
| R-23 | 34 | 41 | 28 | 30 | 34 | 62 | 58 | 60 | 57 | 59 | 54 | 45 | 46 | 70 | 49 | 66 | 13 | 61 | 16 | 60 | 48 | 45 | 29 | 35 | 45 |
| R-24 | 29 | 31 | 23 | 34 | 28 | 53 | 55 | 59 | 48 | 57 | 61 | 57 | 61 | 88 | 83 | 92 | 35 | 69 | 0 | 94 | 44 | 36 | 40 | 34 | 66 |
| R-25 | 41 | 27 | 32 | 24 | 23 | 67 | 67 | 58 | 55 | 57 | 46 | 54 | 56 | 80 | 79 | 83 | 41 | 67 | 55 | 94 | 46 | 31 | 31 | 39 | 46 |
| R-26 | 53 | 40 | 29 | 42 | 40 | 64 | 60 | 62 | 65 | 68 | 58 | 62 | 46 | 90 | 89 | 84 | 42 | 89 | 69 | 97 | 46 | 48 | 39 | 44 | 66 |
| R-27 | 25 | 22 | 38 | 32 | 21 | 49 | 54 | 39 | 58 | 40 | 70 | 67 | 62 | 81 | 86 | 81 | 49 | 71 | 84 | 95 | 30 | 18 | 28 | 32 | 66 |
| R-28 | 42 | 50 | 51 | 43 | 45 | 72 | 72 | 76 | 79 | 74 | 68 | 68 | 76 | 86 | 82 | 86 | 28 | 81 | 82 | 95 | 58 | 46 | 56 | 55 | 65 |
| R-29 | 17 | 12 | 13 | 41 | 15 | 22 | 38 | 40 | 71 | 43 | 57 | 51 | 56 | 80 | 83 | 76 | 26 | 51 | 92 | 81 | 45 | 32 | 24 | 53 | 63 |
| R-30 | 20 | 12 | 42 | 10 | 17 | 61 | 61 | 36 | 27 | 56 | 66 | 67 | 64 | 84 | 85 | 86 | 37 | 77 | 0 | 94 | 51 | 32 | 30 | 27 | 62 |
| R-31 | 8 | 8 | 8 | 11 | 12 | 9 | 9 | 7 | 19 | 13 | 37 | 36 | 42 | 80 | 69 | 78 | 8 | 15 | 0 | 95 | 5 | 6 | 5 | 5 | 45 |
| R-32 | 15 | 12 | 14 | 18 | 17 | 17 | 23 | 19 | 22 | 13 | 49 | 56 | 51 | 48 | 53 | 49 | 22 | 42 | 73 | 86 | 20 | 20 | 15 | 19 | 32 |
| R-33 | 6 | 8 | 7 | 40 | 8 | 20 | 9 | 8 | 10 | 9 | 47 | 50 | 48 | 72 | 64 | 64 | 22 | 9 | 0 | 90 | 6 | 6 | 10 | 35 | 43 |
| R-34 | 43 | 32 | 36 | 33 | 32 | 61 | 65 | 66 | 68 | 60 | 47 | 38 | 40 | 65 | 70 | 65 | 32 | 69 | 0 | 94 | 59 | 54 | 43 | 47 | 60 |
| R-35 | 11 | 9 | 11 | 10 | 14 | 17 | 16 | 16 | 17 | 20 | 61 | 64 | 70 | 70 | 70 | 77 | 39 | 14 | 0 | 94 | 9 | 10 | 12 | 14 | 55 |
| R-36 | 5 | 7 | 4 | 5 | 4 | 16 | 19 | 19 | 12 | 21 | 52 | 50 | 59 | 86 | 81 | 82 | 17 | 28 | 35 | 93 | 10 | 8 | 13 | 9 | 49 |