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# Speech Intelligibility Index and the Ling 6(HL) test: correlations in pediatric hearing aid users

# *Índice de inteligibilidade de fala e teste Ling-6 (HL): correlações em escolares usuários de próteses auditivas*

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**Keywords**

Speech Audiometry
Hearing Aids
Child
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## ABSTRACT

**Purpose:** To evaluate speech audibility in schoolchildren hearing aids users and correlate the Speech Intelligibility Index to phonemes detecion. **Methods:** 22 children and adolescents hearing aids users, underwent audiological evaluation, in situ verification (and consequent obtaining the Speech Intelligibility Index - SII - for conditions with and without hearing aids) and detection thresholds for phonemes by Ling-6 (HL) test. **Results:** The average value for the SII was 25.1 without hearing aids and 68.9 with amplification (p <0.001 *). The phoneme detection thresholds in free field, in dBHL, were, without amplification /m/ = 29.9, /u/ = 29.5, /a/ = 35.5, /i/ = 30.8, /ʃ/ = 44.2 e /s/ = 44.9, and with amplification /m/ = 13.0, /u/ = 11.5 /a/ = 14.3, /i/ = 15.4, /ʃ/ = 20.4 e /s/ = 23.1 (p<0.001*). There was a negative correlation between SII and the thresholds of all phonemes in the condition without hearing aids (p≤0.001*) and between SII and the /s/ threshold with hearing aids (p = 0.036*). **Conclusion:** The detection thresholds for all phonemes are lower than without hearing aids. There is a negative correlation between SII and the thresholds of all phonemes in the situation without hearing aids and between SII and the detection threshold of the phoneme / s / in the situation with hearing aids.

**Descritores**

Audiometria da Fala
Auxiliares de Audição
Criança
Perda Auditiva
Audição

## RESUMO

**Objetivo:** Avaliar a audibilidade de fala em crianças usuárias de próteses auditivas e correlacionar o Índice de Inteligibilidade de Fala à detecção de fonemas. **Método:** 22 crianças e adolescentes usuários de próteses auditivas passaram por avaliação audiológica básica, verificação *in situ* (e consequente obtenção do Índice de Inteligibilidade de Fala - SII - para condições com e sem próteses auditivas) e pesquisa dos limiares de detecção para fonemas por meio do teste Ling-6(HL). **Resultados:** O SII médio foi 25,1 sem próteses auditivas e 68,9 com amplificação (p <0,001*). Os limiares de detecção de fonemas em campo livre, em dBNA, foram, sem amplificação /m/=29,9, /u/=29,5, /a/=35,5, /i/=30,8, /ʃ/=44,2 e /s/=44,9, e com amplificação /m/=13,0, /u/=11,5 /a/=14,3, /i/=15,4, /ʃ/=20,4 e /s/=23,1 (p <0,001*). Houve correlação negativa entre SII e os limiares de todos os fonemas na condição sem próteses (p≤0,001*) e entre SII e o limiar do /s/ com próteses (p = 0,036*). **Conclusão:** Os limiares de detecção de todos os fonemas são menores do que na condição sem próteses. Há correlação negativa entre SII e os limiares de todos os fonemas na situação sem próteses e entre SII e o limiar de detecção do fonema /s/ na situação com próteses auditivas.

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## INTRODUCTION

Early diagnosis of hearing loss in children and rapid intervention are decisive in ensuring proper communication development. Early childhood is a critical time for brain maturation and the strengthening of synaptic connections, determined by the child's sound experience.

The amplification supplied by hearing aids provides the necessary stimulation to make better use of the plasticity of the central nervous system and enables the overall development of those with hearing loss. Successful hearing aid fitting depends on an analysis of the benefits to the user. Speech therapists are responsible for assessing and identifying hearing improvements in children who use amplification. Knowing the measurements used to adjust pediatric amplification in speech therapy practice is a vital part of the therapeutic process to ensure language development[1]. This can be achieved through subjective or objective measures, the latter dependent or not on patient response.

User-dependent objective measures include observing behavioral responses to the amplified signal provided by the hearing aids, quantifying these responses by examining hearing thresholds under free field conditions and testing the aided audibility of speech sounds, such as the Ling sounds proposed by Daniel Ling, which include the low, medium and high frequency phonemes typically present in speech[2,3].

The six phonemes in the test are /m/, /oo/, /ah/, /ee/, /sh/ and /s/, presented aloud in free field, and can be used to assess different auditory skill levels through four tasks: detection, discrimination, identification and repetition[4,5]. The stimuli are validated and natural, which makes it possible to assess aided hearing thresholds considering the modern signal processing of current hearing aids.The acoustic characteristics of each of the phonemes in the test are presented in Chart 1 – adapted[4].

These phonemes were used to create the Ling-6 (HL) test, a calibrated version of naturally produced speech sounds to measure detection thresholds.The test was recorded on a CD at the Western University Child Amplification Laboratory and is used in hearing aid fitting[6].

Objective methods that do not depend on user participation include in situ measurements using a probe-tube microphone and speech stimulus. Increasingly applied in Brazil, the main advantage of this approach is in assessing the ability to access speech sounds within the dynamic range of human hearing, using hearing aids adjusted to the wearer's normal use of the devices in everyday life via real-life stimuli such as recordings of spontaneous speech, music and texts. These measurements are used to obtain the speech intelligibility index (SII), which quantifies the proportion of speech information audible to the listener.

**Chart 1.** Acoustic characteristics of the Ling sounds

| Phoneme | F1 (Hz) | F2 (Hz) | Energy concentration frequency (Hz) |
|---|---|---|---|
| /m/ | | | 250-350 |
| /oo/ | 459 | 1105 | |
| /ah/ | 936 | 1551 | |
| /ee/ | 437 | 2761 | |
| /sh/ | | | 4500 |
| /s/ | | | 8000 |

Despite having gained ground only in the last decade, the SII has its origins in the early 1940s. Estimated speech intelligibility was first calculated in the engineering department of the Bell Telephone Laboratories in order to improve speech transmission via communication systems, producing the first formula for the Articulation Index (AI), which was not widely used due to its complexity[7]. The goal of the AI was to quantify the relationship between the portion of the speech spectrum that remains audible in the presence of filters, distortions and noise.

Following several studies and changes to the original formula, the American National Standards Institute (ANSI 3.5-1969) published the first validation of the AI[8], considering it a proportional index based on the audibility of weighted speech bands in silence and in the presence of competitive noise.The index varies from 0.0 to 1.0, with 0.0 indicating that none of the speech sounds are audible and1.0 maximum audibility.Until then, each decibel of audibility had the same weight in determining the AI, regardless of its location on the frequency band.

A series of revisions to the AI led to the Count-the-Dots method[9], which attributes different weights to audible frequencies according to their importance in speech comprehension. The Count-the-Dots audiogram contains 100 points (46 in the frequency range above2000 Hz), distributed over a 30 dB range within the speech frequency spectrum. All the points located above the hearing thresholds are considered audible. The total number of points counted is then divided by 100 and the result is the predicted speech audibility.

Based on modifications to its 1969 standard, the American National Standards Institute (ANSI 1997 [R2012])[10] introduced the Speech Intelligibility Index (SII), which is calculated based on speech and noise spectrum levels as well as hearing thresholds. Factors such as intensity-related distortion and reverberation are also taken into account. Speech and noise signals are filtered into frequency bandsthat contain varying amounts of speech information and therefore contribute differently to intelligibility. The bands are computed according to their frequency importance function, which characterizes the contribution of each band to speech intelligibility. The result is a number from zero to 100 that indicates the amount of speech information available to the listener. The SII can be calculated automatically by hearing aid verification devices (e.g., Verifit ®Audioscan, GN OtometricsAurical®) or through software developed by researchers from the Acoustical Society of America (ASA).

In 2010, the Count-the-Dots method for calculating the SII was revised,with additional points on the audiogram attributed to higher frequencies (6 to 8 kHz) when compared to the 1990 study.The change was the result of research that demonstrated the importance of audibility in regions near or above 8000Hz in recognizing fricative phonemes such as /s/, particularly for female talkers[11].

Objective assessments that are dependent on or independent of hearing aid user behavior should be conducted together. The American Academy of Audiology's Clinical Practice Guidelines for Pediatric Amplification[12] recommend the SII as an important verification tool and standardized method for calculating the audibility of a speech signal, but highlight its tendency to overestimate speech recognition in hearing-impaired children. The same document considers the Ling-6 (HL) an effective quantitative measure of the benefits obtained with hearing aids and suitable for application in children above three years of age, making it an integral part of evidence-based clinical practice.

According to the literature, audibility estimates are insufficient to accurately predict speech recognition in hearing impaired children and hearing loss has additional effects that are not modeled by the SII[13]. The variability of speech intelligibility is especially pronounced in complex listening scenarios, when the auditory system processes a multitude of cues to extract speech information. Although a combination of factors such as hearing loss and type of masking noise contribute to different outcomes, the reasons for this variability are not entirely understood and the individual effects cannot be fully predicted by current speech intelligibility models. These unpredictable results can be explained by sensory processing, cognitive and non auditory processes[14].

The frequency importance functions used to calculate the SII were initially based on data obtained from people with normal hearing thresholds, which could be problematic for calculations involving hearing loss. Sensorineural hearing loss results in suprathreshold deficits that persist even after hearing is partially restored by hearing aid amplification. As such, predictions based solely on audibility may not provide accurate estimates[15]. Several modifications to the SII have been proposed, some of which consider reduced spectral and temporal resolution and auditory processing deficits as residual changes that cannot be resolved by hearing aids[16].

Nevertheless, it is important to note that the same SII values can be obtained under different auditory conditions, with different effects on the hearing behavior of individuals. The SII is an objective method widely used to predict speech intelligibility, with the frequency importance functions (FIF) as a key component. Predictions are essentially based on the audible portion of the speech spectrum, with each frequency band weighted according to its typical contribution (or importance) to intelligibility. The FIF characterizes the relative contribution of different frequency bands to speech intelligibility. Previous studies have shown that the FIF depends on the speech material used. In research conducted in the 1940s, the FIF was initially calculated based on nonsense syllables. The justification for using this stimulus was to ensure that speech intelligibility was determined primarily by the acoustic characteristics of the stimuli and not cognitive traits or other factors (a significant syllable might be recognized by guessing based on prior knowledge, even when a phoneme was not actually heard). In 1959, an FIF was developed for phonetically balanced words, at the time considered a more representative stimulus of everyday language. The results revealed greater weighting of low frequency bands for words than for nonsense syllables. In 1987, an FIF was estimated for continuous discourse, withthe results once again revealing greater importance for low frequency bands than for balanced words[17]. The ANSI S3.5 standard provides six FIFs for six types of discourse, including nonsense syllables, balanced words and short messages[10]. Better or worse speech recognition is determined not by the SII values, but by the audibility in certain frequency bands versus the stimulus.

Studies performed to date have confirmed the importance of objective and behavioral assessment of amplification and patients, respectively, as complementary methods, and research that involves applying and recognizing the valueof these techniques in clinical practice.

As such, the aim of this study was to assess speech audibility in children treated at a specialist hearing health center in the city of São Paulo, Brazil, and correlated the speech intelligibility index with phoneme detection.

## METHODS

The study was registered on Plataforma Brasil (Brazil Platform) and approved by the Research Ethics Committee (CEP) of the Universidade Federal de São Paulo (UNIFESP) under protocol number 706.597.Participants were children whose parents and/or guardians were previously informed of the study objectives and method and who authorized the use of the data collected by signing a consent form, as well as children who were advised of the procedures involved who provided written informed consent.

A cross-sectional exploratory design was used, with convenience sampling.

### Sample

The sample was selected from an electronic list of the medical charts of boys and girls between the ages of 8 and 14 years, fitted with bilateral hearing aids between 2008 and 2013 at the Núcleo Integrado de Assistência, Pesquisa e Ensino em Audição (NIAPEA) of the Escola Paulista de Medicina / Universidade Federal de São Paulo (EPM/UNIFESP). A total of 295 charts were examined to ensure that participants met the following eligibility criteria:

- exhibiting mild to severe stable, prelingual bilateral sensorineural hearing loss[18];
- using bilateral behind-the-ear (BTE) hearing aids for at least one year.

Exclusion criteria wereovert health problems that prevented participation in the assessments (such as cognitive impairment or delays and/or other severe neurological disorders) and other sensory or motor deficits.

Six of the 295 charts were not located in the file and 258 were excluded for not meeting the established inclusion criteria, leaving 31 children.Of these, eight were unable or failed to attend the assessment sessions and one could not be contacted during the study period, totaling 22 children assessed.

**Material**

- Heine Mini3000® otoscope;
- InteracousticsAT235h middle ear analyzer;
- Interacoustics AC33 audiometer with jack connectors (for speakers), coupled to an Itautec desktop DVD RW drive;
- AudioscanVerifit® hearing aid analyzer;
- The Ling-6(HL) Test CD, recorded at the Western UniversityChild Amplification Laboratory, used to measure speech sound detection thresholds calibrated in hearing level and validate hearing aid fitting[6];
- RadioShack digital sound-level meter.

**Procedures**

The ear canal of participants was visually inspected with a HeineMini3000® otoscope to check for any obstruction that might prevent audiological assessment.

This was followed by assessment with pure-tone air (frequencies of 250 to 8000 Hz) and bone conduction testing (sound frequencies of 500 to 4000 Hz), speech audiometryand acoustic immittance measures (tympanometry and contralateral acoustic reflex thresholds at 500 to 4000 Hz). The results were recorded on the standard test form used by the institutions. Hearing loss in each ear was classified according to degree[18] and configuration[19].

Participants using hearings aids were submitted to in situverification in each ear using a speech stimulus and AudioscanVerifit® device. To that end, the following data were input into the Verifit system:the prescriptive method used to program the hearing aids, patient age, transducer used in the hearing test and the thresholds obtained by air conduction from 250 to 6000 Hz (although thresholds have been analyzed up to 8000 Hz, this version of the in situverification software only allows thresholds up to 6000 Hz) and bone conduction from 500 to 4000Hz.The uncomfortable level (UCL) values provided by the device were used, estimated based on the audiometric test.To that end, the Audioscan Verifit® system considers a standard deviation below the average UCL estimated in previous research[20]. Values supplied by the *Verifit®* device were also considered for the real-ear coupler difference (RECD), since individual values were not measured in initial programming of the hearing aids.During the tests, the children were asked to remain seated one meter from the Verifit speaker, at 0º azimuth. The probe-tube microphone was kept at a constant depth of 4 to 5 mm past the end of the earmold. The speech intelligibility index was obtained using an international speech test signal (ISTS) stimulus emitted through the speaker at 65 dBSPL[21].

The device calculated the SII for the aided and unaided speech signal based on the response curves of the hearing aids as a function of the frequencies obtained from the ISTS signal. Aided and unaided SIIs were obtainedfor the left and right ears, producing a total of four values.The maximum power output (MPO) of the hearing aids was also calculated by presenting a series of 128 ms tone bursts at 128ms intervals and 90 dBSPL, as described in the user manual.

The Ling-6 (HL) test was performed in free field in a sound booth, using an Itautec desktop DVD player coupled to an InteracousticsAC33audiometer.The equipment was calibrated and the sound pressure levels measured for each test, as follows:initially, a 1 kHz calibration tone was used and the VU meter of the audiometer adjusted to zero.A RadioShack digital sound-level meter calibrated according to manufacturer specifications was positioned at 0º azimuth in relation to the speaker.The dial of the audiometer was adjusted to 65 dBHL and track two of the CD, consisting of broadband noise, was then played. The sound pressure level was measured in a booth in slow response mode, using an A-weighting filter. A reading of 65 dBHL on the audiometer should correspond to 60dB(A) ± 2 on the sound-level meter. The detection thresholds were determined with speech sounds presented at the suprathreshold levels of each participant, according to standard clinical procedures. Participants were positioned at 0º azimuth, one meter from the speaker, and instructed to raise their hand whenever they heard a sound. The examiner selected the CD tracks corresponding to each Ling sound, which were presented via the audiometer using the ascending-descending method.The procedure was carried out in two scenarios: unaided and bilaterally aided.

In order to obtain normative data, ten normal hearers with no family history of hearing loss or clinical history of noise exposure were submitted to visual inspection of the ear canal followed by hearing screening, which included pure-tone air conduction testing (250 to 8000 Hz) and the Ling-6 (HL) test in free field. The detection thresholds obtained by the listeners for each phoneme of the Ling-6 (HL) produced the correction values presented in Chart 2, which were used to calculate the speech phoneme detection thresholds of the participants.

The corrected thresholds were plotted on an audiogram provided by the CD manufacturer.

The data collected in the procedures were submitted to statistical analysisusing SPSS (the Statistical Package for the Social Sciences) V17, Minitab 16 and Excel Office 2010.The reassessment tests, SII values and phoneme detection thresholds obtained in the Ling-6 (HL) test were analyzed using descriptive statistics.

**Chart 2.** Correction values used to calculate the phoneme detection thresholds in the Ling-6 (HL) Test

| *Ling-6 (HL)* | /m/ | /oo/ | /ah/ | /ee/ | /sh/ | /s/ |
|---|---|---|---|---|---|---|
| Correction value | - 4 | - 3 | - 2,5 | - 1 | - 6 | - 6 |

The qualitative (categorical) variables were expressed as absolute (N) and relative (%) frequencies and the quantitative variables as mean, median, coefficient of variation (CV), minimum and maximum values; first and third quartiles and confidence interval (CI).

Given the small sample size and non-normal data distribution, the nonparametric tests listed below were used for data analysis.

Two proportion z-test: to compare the distribution of the degree and configuration of hearing loss in the left and right ears.

Wilcoxon test: to compare aided and unaided values for the SII and the detection thresholds obtained in the Ling test.

Spearman's test and the correlation coefficient (r): to assess possible correlations between the SII and detection thresholds for the Ling sounds.Based on the distribution of the variables studied, a correlation of 0-0.2 was considered very poor; 0.21-0.4 poor; 0.41-0.6 fair; 0.61-0.8: good; 0.81-1.0: excellent[22].

Significance was set at 0.05 (5%) and confidence intervals at 95%.

## RESULTS

The results of audiological reassessment showed no difference in the frequency of the different degrees of hearing loss between the left and right ears,with moderate impairment most prevalent in both (16 instances or 72.7% and 13 instances or 59.1%, respectively; p-value=0.340). Additionally, no difference was observed between the left and right ears for hearing loss configuration, with the most prevalent being sharply sloping (eight instances on each side, or 36.4%; p-value=1.000), followed by mild sloping (five instances on the right, or 22,7%; and four on the left, or 18.2%; p-value = 0.709).

Following audiological assessment and in situ verification of the hearing aids with the settings typically used by the patients, the SII was measured for each child in the ear with the best hearing (determined for each patient based on hearing thresholds).This procedure was adopted because the Ling-6 (HL) test was performed in free field, when the sensitivity of the ear with the best response is known to be decisive in the result obtained.

A complete descriptive analysis and comparison of the aided and unaided SII values for the best-performing ear are shown in Table 1.

There was a statistically significant difference between aided and unaided SII values for the best ear, whereby average values were lower without hearing aids.

Complete descriptive analysis was performed for the aided and unaided detection thresholds of each phoneme in the Ling-6(HL) test in free field and the results were compared.The results are shown in Table 2.

A statistically significant mean difference was observed between aided and unaided conditions for the detection thresholds of all the Ling-6(HL) phonemes, with average values always higher when the participants were using hearing aids. The difference between the two conditions varied from 15.4 to 23.8 dB.

**Table 1.** Comparison between aided and unaided SII values for the best-performing ear

| SII | | Mean | Median | Q1 | Q3 | N | CI | p-value |
|---|---|---|---|---|---|---|---|---|
| Best ear | Unaided | 25.1 | 20 | 13 | 35 | 22 | 18.6 to 31.6 | <0.001* |
| | Aided | 68.9 | 69 | 64 | 75 | 22 | 65.3 to 72.5 | |

Wilcoxon test
Caption: Q1 = first quartile; Q3 = third quartile; N = number; CI = Confidence interval;* = p<0.05

**Table 2.** Comparison of aided and unaided detection thresholds for each of the phonemes in free field

| LING | | Mean | Median | Q1 | Q3 | N | CO | Aided and unaided difference (Delta) | p-value |
|---|---|---|---|---|---|---|---|---|---|
| /m/ | Unaided | 29.9 | 31 | 21 | 36 | 22 | 24.1 to 35.7 | 16.9 | <0.001* |
| | Aided | 13.0 | 11 | 6 | 21 | 22 | 8.8 to 17.2 | | |
| /u/ | Unaided | 29.5 | 30 | 22 | 36 | 22 | 23.9 to 35.1 | 18.0 | <0.001* |
| | Aided | 11.5 | 7 | 7 | 17 | 22 | 7.7 to 15.3 | | |
| /a/ | Unaided | 35.5 | 38 | 29 | 46 | 22 | 29.1 to 41.9 | 21.2 | <0.001* |
| | Aided | 14.3 | 13 | 9 | 18 | 22 | 11.2 to 17.4 | | |
| /i/ | Unaided | 30.8 | 34 | 24 | 39 | 22 | 26.4 to 35.2 | 15.4 | <0.001* |
| | Aided | 15.4 | 14 | 9 | 23 | 22 | 12.0 to 18.8 | | |
| /ʃ/ | Unaided | 44.2 | 44 | 39 | 49 | 22 | 40.6 to 47.8 | 23.8 | <0.001* |
| | Aided | 20.4 | 19 | 19 | 24 | 22 | 17.9 to 22.9 | | |
| /s/ | Unaided | 44.9 | 47 | 34 | 54 | 22 | 39.6 to 50.2 | 21.8 | <0.001* |
| | Aided | 23.1 | 24 | 15 | 29 | 22 | 19.7 to 26.5 | | |

Wilcoxon test
Caption: Q1 = first quartile; Q3 = third quartile; N = number; CI = Confidence interval;* = p<0.05

**Table 3.** Correlation between aided and unaided SII and Ling 6-HL results

| SII Best Ear | | Unaided | Aided |
|---|---|---|---|
| m | Corr (r) | -0.768 | -0.172 |
| | p-value | <0.001* | 0.444 |
| oo | Corr (r) | -0.718 | -0.240 |
| | p-value | <0.001* | 0.281 |
| ah | Corr (r) | -0.825 | -0.118 |
| | p-value | <0.001* | 0.600 |
| ee | Corr (r) | -0.559 | -0.173 |
| | p-value | 0.001* | 0.441 |
| sh | Corr (r) | -0.747 | -0.302 |
| | p-value | <0.001* | 0.172 |
| s | Corr (r) | -0.649 | -0.449 |
| | p-value | 0.001* | 0.036* |

Correlation coefficient and Spearman's test
Corr (r): Spearman's correlation;* = $p<0.05$

Detection thresholds were higher for the fricative phonemes both with (average of 20.4 and 23.1 dBHL) and without hearing aids (average of 44.2 and 44.9).

Greater gains were observed for the fricative phonemes /sh/ and /s/ (23.8 and 21.8 dB, respectively), which are the most important in speech intelligibility, when compared to vowels and nasal sounds (/m/: 16.9; /oo/:18.0; /ah/: 21.2; /ee/: 15.4 dB).

Correlations between the SII and detection thresholds for each of the Ling-6(HL) phonemes were assessed under aided and unaided conditions.The possible correlations calculated using the correlation coefficient and Spearman's test are shown in Table 3.

Correlation values (r) vary from -1 to 1.All the cases analyzed exhibited a negative correlation, indicating that the variables are inversely proportional, that is, when one increases the other declines, and vice versa. As such, the higher the SII, the lower the phoneme detection threshold. Significant fair to excellent correlations were observed between the SII and detection thresholds for all the Ling-6(HL) phonemes without hearing aids (fair for /ee/; good for /oo/, /m/, /sh/ and /s/ and; excellent for /ah/). There was a significant fair correlation between the SII and detection thresholds for /s/ under aided conditions.

## DISCUSSION

In a study with 64 children, the average aided SII for medium-intensity sounds in the best ear was 74.9[23].According to the literature, SII values below 35 hamper the development of canonical babbling, that is, the vocalization of consonants[24].

There was a statistically significant mean difference between aided and unaided conditions for the detection thresholds of all the Ling-6(HL) phonemes, with average values always higher when the participants were using hearing aids and the difference between the two conditions varying from 15.4 to 23.8 dB. Similar results were obtained in a previous study of 29 children with sensorineural hearing loss aged between 3 and 15 years, whereby gains varied from 13 to 26 dB[25].

Detection thresholds were higher for the fricative phonemes both with (/sh/ = 20.4 dBHL and /s/ = 23.1 dBHL on average) and without hearing aids (/sh/ = 44.2 dBHL and /s/ = 44.9 dBHL on average). The higher threshold attributed to these phonemes is justified by the fact that sloping hearing loss was most prevalent in the population assessed.Fricative phonemes fall within the same frequency range as the hearing loss of most of the children studied here, namely above 2000Hz[26]. The literature emphasizes the relevance of frequencies near or above 8000Hz in the detection of fricative phonemes such as /s/, particularly for female talkers[11].

Studies also underscore the importance of audibility at high frequencies and its implications for speech and language development.Frequencies above 1000Hz contribute to only 5% of speech energy and 60% of intelligibility[27]. Inconsistent exposure to these sounds during early childhood may influence or delay speech production and the formation of linguistic rules, such as the use of the plural form[28]. As a result, it is vital to assess how well hearing aids are fitted, especially in this frequency range. Other authors have reported that children with hearing aids can perceive vowel sounds well, even when the gain and output settings differ from those prescribed; however, after the modification of electroacoustic characteristics to match prescribed measures, the average percentage of correct responses for words, consonants and traces increased[29].

Greater gains were observed for the fricative phonemes /sh/ and /s/ (23.8 and 21.8 dB, respectively), which are the most important in speech intelligibility, when compared to vowels and nasal sounds (/m/: 16.9; /oo/:18.0; /ah/: 21.2; /ee/: 15.4 dB). Similar values were recorded in a previous study, with greater gains for fricatives (/sh/: 26.1 and /s/: 24.1 dB) when compared to the other phonemes (/m/: 14.7, /oo/: 13.5, /ha/: 18.3, /ee/: 13.4 dB)[25]. Thus, sound amplification fulfilled its purpose in the children studied here and significantly improved the audibility of phonemes.

The Count-the-Dots method is important in understanding the correlation between the two assessments (the SII and Ling test)[9,11] and serves as the basis for calculating the SII, according to the American National Standards Institute[10]. The method attributes different weights to audible frequencies according to their importance in speech recognition. To that end, 100 points are plotted on an audiogram, with almost half located above the highest frequencies (above 2000 Hz), demonstrating a greater contribution to speech intelligibility.Most of the energy of fricative phonemes is also concentrated above 2000 Hz[11,26]. Thus, under aided conditions, the correlation between the perception of fricative phonemes and the SII is more important because it indicates greater compatibility between the gains that the hearing aid provides and what the individual can hear. Additionally, since hearing loss in the participants is predominantly sloping, it can be inferred that the correlation observed for /s/ occurred because the greatest change in hearing possibilities under aided conditions took place within the concentration range of this phoneme, with effects of a smaller magnitude for the remaining phonemes whose energy is concentrated in other frequency ranges.

Similarly to the present study, an investigation that correlated the SII with behavioral measurements in 41 children found that babies with an SII between 36 and 55% are more affected when the level of the stimulus input signal is altered[30].

Several studies with different objectives have demonstrated the need for better audibility in children than the predicted SII for adults to ensure equal performance in speech recognition tasks in the presence of noise[13].

Despite the efforts made in data collection, the main limitation of the present study is the small sample size, which is justified in the methods section.Other important limitations were the lack of a control group and not controlling variables such as intelligence quotients and socioeconomic status.

## CONCLUSION

Phoneme detection thresholds are lower without hearing aids.Although hearing aids provided greater gains for fricatives, these speech sounds have higher thresholds than the remaining phonemes because their energy levels are the lowest of those assessed.

There is a negative correlation between the unaided SII and detection thresholds for all the phonemes studied and between the SII and the /s/ detection threshold with hearing aids,whereby the detection thresholds decline when the SII increases.Based on these findings, it can be inferred that the greatest change in audibility possibilities under aided conditions occurs at high frequency ranges, which is consistent with the needs of most of the study population given the configuration of their hearing loss.

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## Author contributions

*MRFS study design, data collection, drafting the article (part of a doctoral thesis), submission; MCMI study design, advisor on the thesis that generated the study, suggestions and necessary corrections.*