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Original Article

Artigo Original

Hearing loss classification by degree, configuration and relationship with amplified Speech Intelligibility Index (SII)

Classificação de perdas auditivas por grau e configuração e relações com Índice de Inteligibilidade de Fala (SII) amplificado

Renata de Souza Lima Figueiredo[1]
Beatriz Mendes[1]
Maria Carolina Versolatto Cavanaugh[1]
Beatriz Novaes[1]

Keywords

Speech Intelligibility
Hearing Aids
Hearing Loss
Child
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ABSTRACT

Purpose: To establish the relationship between speech intelligibility index (SII) values generated at the verification of hearing aids programmed according to DSL*m* [i/o] v5 prescription rule and a proposed individual classification that considers the combination of hearing loss degree and configuration. **Methods:** Forty-one children aged between 4 and 80 months were selected, totaling 78 ears for analysis. We considered hearing thresholds at the frequencies of 250, 500, 1000, 2000 and 4000 Hz; and analyzed values of the Speech Intelligibility Index (SII) for the input signal of 65 dB SPL obtained during the verification of hearing aids using the equipment Verifit®Audioscan. **Results:** Hearing losses were classified into five homogeneous groups regarding audiometric degree and configuration. The groups were heterogeneous when compared to each other. From the groups, three ranges of SII values were determined. Equations were developed for classification of hearing loss according to groups and for determination of the adjusted SII values. **Conclusion:** The SII value is a useful indicator of audibility for speech sounds in different characteristics of hearing losses, and can guide observations of auditory skills. The SII has stronger relationship with the association of the audiometric degree and configuration when compared with degree of hearing loss alone.

Descritores

Inteligibilidade de Fala
Auxiliares de Audição
Perda Auditiva
Criança
Reabilitação de Deficientes Auditivos

RESUMO

Objetivo: estabelecer relações entre valores do índice de inteligibilidade de fala - SII gerados na verificação dos aparelhos de amplificação sonora programados conforme regra prescritiva DSL*m*[i/o]v5 e uma proposta de classificação de indivíduos que considere a associação de grau e configuração de perdas auditivas. **Método**: foram selecionadas 41 crianças com idades entre 4 e 80 meses, totalizando 78 orelhas para análise. Foram considerados os limiares auditivos nas frequências 250, 500, 1000, 2000 e 4000 Hz e analisados valores de SII para os sinais de entrada 65 dB NPS, obtidos na verificação dos AASI no equipamento Verifit®Audioscan. **Resultados:** as perdas auditivas foram classificadas em cinco grupos homogêneos quanto às características audiológicas (grau e configuração audiométrica) e heterogêneos entre si. A partir dos grupos, determinaram-se três intervalos de valores de SII. Foram determinadas equações para classificação da perda auditiva conforme grupos e equações para determinação de valores de SII ajustado. **Conclusão:** o valor de SII pode ser considerado um indicador da audibilidade para sons de fala para diferentes características de perdas auditivas e nortear avalições de comportamento auditivo. O SII tem relação mais forte com a associação das variáveis grau e configuração audiométrica, quando comparado com sua relação com o grau da perda auditiva isoladamente.

Corresponding author:
Renata de Souza Lima Figueiredo
Rua Estado de Israel, 1056, Vila Clementino, São Paulo (SP), Brazil, CEP: 04022-002.
E-mail: rsl.figueiredo@gmail.com

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[1] Pontifícia Universidade Católica de São Paulo – PUC-SP - São Paulo (SP), Brazil.

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INTRODUCTION

The main objective of the hearing aid selection process in infants and children with hearing loss is to provide audibility to speech sounds and, thus, foster the development of oral language[1].

The hearing aid (HA) selection process in infants and young children is composed of integrated and sequential steps[2,3], namely: definition of hearing thresholds, selection of electroacoustic characteristics of amplification, verification of amplification and, finally, validation. These steps, well known by professionals, are systematically described in available protocols of good practice in pediatric audiology[4-6].

It is in the third step of the HA selection process that the adequacy of amplification is verified according to the prescriptive method selected. Studies show that there are large differences among the software provided by manufacturers of HA. Consequently, for the same hearing loss, different values of gain and output are calculated, which confirms the need for the verification step[7,8].

It is important to evaluate the audibility of speech signal in HA selection process to ensure that infants and children with hearing loss have access to speech sounds with quality and without discomfort, using objective and subjective measurements[9]. However, infants and young children are not yet able for traditional speech recognition tests and other validation methods used with adults and older children. Audiologists must, then, rely on objective measurements and procedures, obtained in the HA verification step, to estimate audibility to speech sounds. The verification step can further contribute to adjust expectations towards auditory development, considering other complex variables, and psychological development.

One such measure is the Speech Intelligibility Index (SII), which determines the proportion of audible and useful speech information available to the listener, with high correlation with speech intelligibility[10]. Emerged from the review made in 1997 of ANSI S3.5-1969, the SII replaced the best known Articulation Index (AI) which, by the end of the 80s, was not widely used clinically due to the complexity of calculation. The advancement of technology has enabled the clinical use of the SII to the extent that the HA verification equipment (Verifit®Audioscan, Interacoustics Affinity®) displays the automatic calculation during the verification procedure[6]. Alternately, the SII can be determined with the use of software developed by researchers at the Acoustical Society of America (ASA).

SII is calculated from the speech signal spectrum, the noise spectrum and the hearing threshold of the subject. Speech signals and noise are filtered into frequency bands. Within each frequency band, the audibility factor is derived from the signal to noise ratio, indicating the degree to which the speech signal is audible. A SII value of zero means that no speech sound is audible while a score of 100% means that all the speech information is available[10].

The use of SII is more common in audiology clinical practice as an aid tool in verifying output target for speech stimuli at different intensities and as a strategy for family guidance as a predictor measure of audibility to speech sounds in different types of sound environment[6,11].

When describing the DSL*m* [i/o] v5 prescription and the presentation of the first results of the application of the method, study[12] exposed some results on the analysis of the values of amplified SII compared to the average of hearing thresholds from 2000 to 6000 Hz using the Verifit®Audioscan equipment. The conclusion was that the SII values are directly related to the mean thresholds analyzed: as the average of the thresholds increases, the SII decreases and vice versa. In general, the SII values are better than 60% for hearing loss up to 75 dB HL. For hearing losses higher than 80 dB HL, SII values may vary from 20 to 60%, depending on the configuration of the loss, the test signal level and the target output difference.

Other studies have aimed to relate the values of SII directly with the development of language and with the scores of speech recognition in children. Bass-Ringdahl[13] reported that infants with less than 35% of SII do not develop canonical babble. Researchers[12,14] reported the need to be careful in relating the SII directly with scores of speech recognition in children. In general, children need more audibility to achieve the same speech recognition scores than adults because they are in the process of language development and have less dominance of oral language. Therefore, the relationship between SII and speech recognition is not straightforward. The SII is an objective measure related solely to hearing, while tests of speech recognition involve other variables related to the characteristics of speech materials and the stage of development of each child, along with their individual characteristics.

Studies[15-17] aiming to investigate the relationship between the values of SII and speech recognition scores for different test materials with certain characteristics frequency, concluded that the frequency importance function (FIF) - required by ANSI[10] for six types of speech materials - must also be established for other types of test materials so that the speech recognition scores can be related to the values of SII. These results suggest that, in addition to the degree of hearing loss, audiometric configuration is essential to trace prognosis of audibility and intelligibility of speech.

Therefore, for comparative analyzes between amplified SII values and hearing loss, it seems that to only consider the degree obtained from the average of some frequencies does not accurately reflect the relationship between amplified SII and auditory characteristics.

In this perspective, considering:

- that the SII estimate speech intelligibility, although it has limitations inherent the complexity of the phenomenon under measurement;
- that the SII is available in most equipment used by audiologists; - that the validation process involves complex factors relating to associated disorders and sensory motor and emotional development;

- that in public policies in Brazil, the professionals involved in the therapeutic process very often do not have specific knowledge about audiological measures, and that process of selection and adjustment of HA, are performed in specialized centers, this study aims at contributing to the stage when the audiological information set and characteristics of development of every child can guide the expectations of clinicians and families regarding the development of oral language.

This study aims to conduct a comparative analysis between SII values for the input of 65 dB SPL generated during the verification of HA devices programmed according to the DSL*m*[i/o] v5 prescription and a proposed classification that considers the association of the variables degree and configuration of hearing loss, in order to use as an indicator that may guide the observation of auditory skills likely considering complex factors involved in the child population, during the first stages of the validation process.

METHODS

This study was conducted at the Center of Child Hearing (Centro Audição na Criança - CeAC)†. It is a high complexity service accredited by the Unified Health System (Sistema Único de Saúde - SUS) that provides care to children with suspected or confirmed hearing loss who are below three years of age. This study followed the precepts established by the code of ethics for human research and was approved by the ethics committee of PUC-SP, according to the research protocol number 337/2010.

The study included 41 patients, aged between four and 80 months, diagnosed with sensorineural hearing loss of any degree and configuration who participated in the selection of hearing aids during the year 2011, totaling 78 ears for analysis. Of this total, two ears of subjects with cochlear implant and two ears of two subjects with anacusis were excluded. Nonlinear hearing aids were indicated for all children.

Procedures

Determining hearing thresholds

Hearing thresholds used in programming (PT) of the devices were determined from the audiological evaluation according to the protocol established by the professionals of the institution. The thresholds used in the analysis were: 250, 500, 1000, 2000 and 4000 Hz. When the responses to frequencies were absent until the limit of the equipment, the values considered were recorded on the Noah® software for programming the hearing aid. The program generally uses the maximum values of the AC-33 audiometer from Interacoustics: for the frequency 250 Hz, the maximum of the equipment is 105 dB; to 500 Hz, 110 dB; for 1000, 2000 and 4000 Hz, 120 dB. For ears in which the frequency 250 Hz was not recorded, the 250 Hz threshold was considered equal to that of 500Hz.

Obtaining SII values

The hearing aids were selected and programmed based on the thresholds established during the diagnostic process through the DSL*m* [i/o] v5 prescription. RECD measures were carried out with the ear molds. When this was not possible, the values predicted by the Verifit®Audioscan equipment were used.

With hearing thresholds and RECD (measured or predicted), the HA were programmed via the software of their respective companies. Technologies such as nonlinear frequency compression or frequency transposition were disabled when available for the model of HA.

The verification of measures for speech sounds of 55, 65 and 75 dB SPL and for maximum output (90 dB SPL) were carried out on the Verifit®Audioscan. The speech stimuli used was the Standard-speech (Speech-std 1) - Carrot passage. The difference of 3 dB positive or negative was used to determine similar values between the electroacoustic characteristics of gain and output prescribed by the DSL*m* [i/o] v5 software and values found in the HA. Exceeding these values can result in super- or sub-amplification(12). The relationship of the difference between the response generated by the amplification devices and targets prescribed under rule DSL*m*[i/o] v5 was analyzed and described in the study "Reference Values for the SII amplified according to rule DSL*m*[i/o] v5"(18). The results showed the impact of the degree of hearing loss in the difference between the amplified response curve and the prescribed targets: severe and profound hearing losses, due to the reduced dynamic range feature differences considered inappropriate amplification. However, this difference does not reflect inadequacy, since the limitation is imposed by the degree of hearing loss (dynamic field of hearing). When we assess the adequacy of the amplification, loudness is related to amplified hearing thresholds and how close hearing aid response curve is to prescribed targets.

For the current study, only the values of SII to speech stimuli at 65 dB SPL were used. Therefore, from this point, only the acronym SII 65 will be used in reference to the values of SII 65dBSPL studied here. The SII 65 values for each tested ear were obtained in the HA verification process, totaling 78 SII 65 values.

DATA ANALYSIS

† Centre associated to the Divisão de Educação e Reabilitação dos Distúrbios da Comunicação (Division of Education and Rehabilitaion of Communication Disorders) of Pontifícia Universidade Católica de São Paulo – DERDIC/ PUC-SP, to the Programa de Estudos Pós-Graduados em Fonoaudiologia/ Linha de Pesquisa Audição na Criança (Graduate Study Program in Speech-Language and Hearing Sciences/Research Line Child Hearing) of Faculdade de Ciências Humanas e da Saúde PUC-SP.

Determination of algorithm with sensitivity to clusters according to auditory threshold and configuration of hearing loss

The technique of cluster analysis [19] was applied with the aim of composing internally homogeneous groups of individuals regarding the hearing thresholds at 250, 500, 1000, 2000 and 4000 Hz and heterogeneous among each other. The k-means method was adopted. The technique was applied considering from two to seven groups. In each group, the within groups sum of squares, which is a measure of internal heterogeneity, was calculated: the larger the sum of squares, the less homogenous are the groups; the larger the number of groups, the smaller is the sum of squares. Based on this sum, the optimum number of groups was obtained. These groups were then characterized according to hearing threshold at different frequencies, degree of hearing loss and SII 65 values.

The technique of discriminant analysis was applied with the purpose of obtaining a rule for classifying a new individual into one of the groups. The cross validation method was used to calculate the percentages of sample individuals correctly classified[19].

Relation between SII 65, mean hearing thresholds and hearing thresholds at the frequencies studied

The Pearson correlation coefficient[20] was considered as a measure of correlation between variables: SII values, mean hearing thresholds and hearing thresholds at the frequencies studied.

The procedure of forward selection of variables[21] was adopted for the fit of the regression model with the aim of describing the relationship between SII and thresholds at 250, 500, 1000, 2000 and 4000 Hz.

Determining SII 65 interval values for prognosis of speech sounds audibility

The first range of SII 65 (Int_{SII}) values that distinguished the groups was established from the cluster analysis and the analysis of relationships between SII 65 and hearing thresholds. To establish the other intervals (Int_{SII}), the value that maximizes both the percentages of correct classification among groups was established based on values and the relationship between sensitivity and specificity[22]. This allowed to study the variation of sensitivity and specificity and to establish a cutoff value. Thereafter, the terms "*sensitivity*" and "*specificity*" were replaced by the expression "*likely to classify a given ear in a given group*" confirming that ear really belonged to that group.

RESULTS

Composition of groups, analysis of the degree of hearing loss according to group and discriminant analysis

Concerning group composition, the value of the sum of squares decreases as the number of groups increases. After five groups, the value of the sum of squares tends to stabilize, indicating that the optimal number of groups is five, because from that number little is gained in relation to the internal homogeneity of the groups. Individual profiles of hearing thresholds in each group at the analyzed frequencies (250, 500, 1000, 2000 and 4000 Hz) are shown in Figure 1.

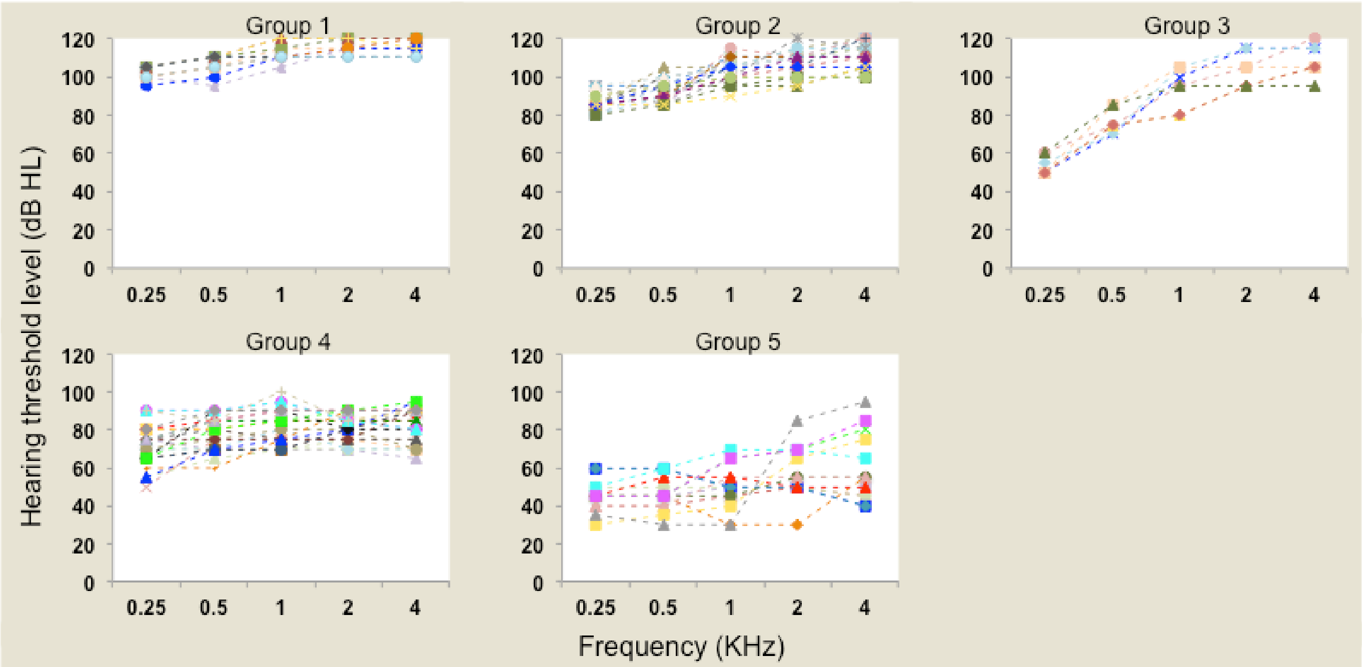

Figure 1. Individual audiometric curves (dB HL) according to frequency (kHz) for groups (Gr1, Gr2, Gr3, Gr4 and Gr5)

The average of the frequencies 500, 1000, 2000 and 4000 Hz was used to classify the degree of hearing loss according to WHO[23].

Classification rules using the technique of discriminant analysis were obtained in order to allow the classification of a new individual into one of the groups established by cluster analysis.

This technique provides, for each group, a function of the thresholds in these frequencies that is called discriminant function. When knowing the thresholds of an individual at these frequencies, it is possible to calculate, in each group, the corresponding values of discriminant functions, called discriminant scores. The individual is classified in the group in which he/she obtains the highest score.

The discriminant functions obtained were:

Group 1: -242.9 + 1.1 x PT 0.25 + 1.9 x PT 0.5 – 0.5 x PT 1 + 0.8 x PT 2 + 1.2 x PT 4;

Group 2: -195.3 + 0.9 x PT 0.25 + 1.6 x PT 0.5 – 0.4 x PT 1 + 0.7 x PT 2 + 1.1 x PT 4;

Group 3: -148.4 + 0.2 x PT 0.25 + 1.6 x PT 0.5 – 0.2 x PT 1 + 0.8 x PT 2 + 0.9 x PT 4.

Group 4: -124.7 + 0.7 x PT 0.25 + 1.4 x PT 0.5 – 0.3 x PT 1 + 0.5 x PT 2 + 0.9 x PT 4;

Group 5: -54.4 + 0.5 x PT 0.25 + 0.9 x PT 0.5 – 0.3 x PT 1 + 0.4 x PT 2 + 0.6 x PT 4.

where PT 0.25, PT 0.50, PT 1, PT 2 and PT 4 are hearing thresholds at 250, 500, 1000, 2000 and 4000 Hz, respectively.

Each ear of the sample was classified by means of the above functions, resulting in a classification matrix. The overall percentage of correct classification was 92%. This high percentage is one more indicative that the number of groups considered in this study is appropriate.

Relations between SII 65, hearing thresholds at frequencies studied and mean auditory thresholds at different frequencies according to groups generated in the cluster analysis

Values of the Pearson correlation coefficient were calculated at each frequency to study the relationship between the values of SII 65 and hearing thresholds. The threshold for 2000 Hz has the strongest correlation with SII 65. There is also a strong correlation between thresholds at the different frequencies studied (Figure 2).

Figure 2 displays the relationship between SII 65 and the threshold at different frequencies.

A regression model was adjusted with SII 65 as the dependent variable and the thresholds at different frequencies as explanatory variables[21]. The forward method of selection of variables was used to fit the model. In each step of this method, an explanatory variable was added to the model. In the first step, the variable most highly correlated with SII 65 was added (threshold at 2000 Hz). The second variable to enter the model was the one that had the largest additional contribution to the first to explain the response variable. The procedure continued until no additional explanatory variable had a significant contribution to the model to explain the response variable. A summary of the results obtained in each step is presented in Table 1.

The threshold at 2000 Hz was selected in the first step. In the second step, the threshold at 500 Hz was added to the model. In the third, the threshold at 4000 was added and in the fourth step the threshold at 1000 Hz. All of these thresholds have significant contribution to explain the SII 65. The threshold at 250 Hz had no significant additional contribution to explain the SII 65 ($p = 0.966$).

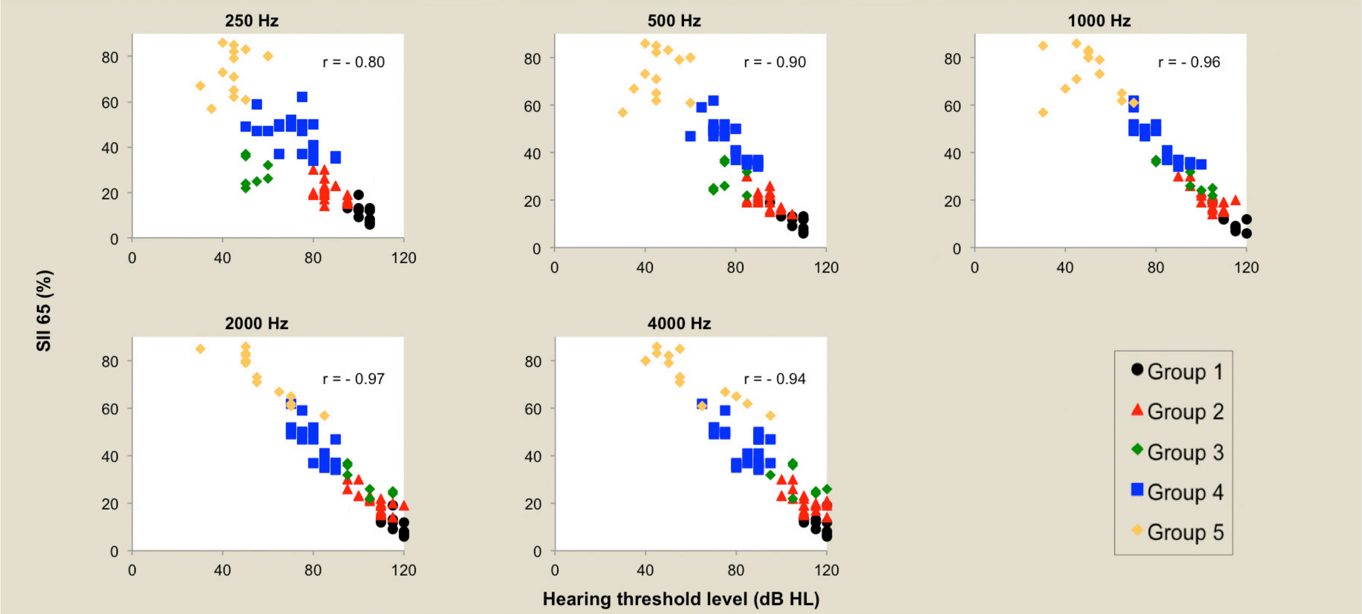

Figure 2. Scatter diagram of SII 65 values and thresholds at frequencies 0.25, 0.5, 1, 2 and 4 kHz ($p<0.001$)

From the third step, variance inflation factor (VIF)[21] values greater than 10 occurred, indicating that the strong correlation between the explanatory variables may be influencing the results. The increase in R^2 from the third step was small. Thus the model adjusted at the second step was considered as the final model:

SII 65 adjusted = 130.35 -0.71 x Threshold 2 kHz - 0.36 x Threshold 0.5 kHz

This equation can be used to predict the value of the SII 65 from the thresholds at 500 and 2000 Hz.

Considering the individual values of SII 65, the values of the Pearson correlation coefficient between the two variables were analyzed: for the average of 500, 1000 and 2000 Hz, a coefficient of -0.98 ($p < 0.001$) was found; for the average of 500, 1000, 2000 and 4000 Hz, the value of -0.99 ($p < 0.001$); and the value of -0.98 ($p < 0.001$) for the average of the frequencies including the frequency of 250 Hz. These values indicate the existence of almost perfect linear relationship between SII 65 and the three mean hearing thresholds. The negative correlation indicates that the higher the average of hearing thresholds, the lower the SII 65 value.

A scatter diagram was constructed to observe the behavior of SII 65 regarding the average thresholds of 500, 1000, 2000 and 4000 Hz (Figure 3). This average was selected because it had greater linearity and because the frequency 250 Hz was excluded from the analysis for not bringing significant additional contribution to explain the SII 65, as can be seen in Figure 3.

The lowest average of thresholds and the highest values of SII 65 were observed in Gr5. Although Gr3 did not differ from Gr4 regarding the mean threshold, Gr3 tended to show lower values of SII 65. Gr1 and Gr2 presented higher mean thresholds and lower values of SII 65. Gr5 and Gr4 were the most heterogeneous groups regarding SII 65 values.

With the aim of characterizing groups and degrees of hearing loss regarding the values of SII, the descriptive statistics of SII 65 per group and per degree of hearing loss were calculated (Table 2).

From the formation of the five groups by the cluster analysis, a comparative analysis between the SII 65 values obtained during the verification of HA and hearing loss characteristics (degree and configuration) was performed.

The scatter plot (Figure 3) and the descriptive statistics of SII 65 values per group (Table 2) show that Gr4 and Gr5 differ from Gr1, Gr2 and Gr3 for presenting higher values of standard deviation. The higher the classification of the group (one to five) the higher the standard deviation values of SII 65. The groups are homogeneous regarding audiological features, but heterogeneous with respect to the amplified SII, especially Gr4 and Gr5.

However, when SII 65 values are analyzed according to the degree of hearing loss, Table 2 reveals that the standard deviation values of SII 65 do not increase according to the degree of hearing loss. This seems to be related to the importance of the association of both variables, degree and configuration of

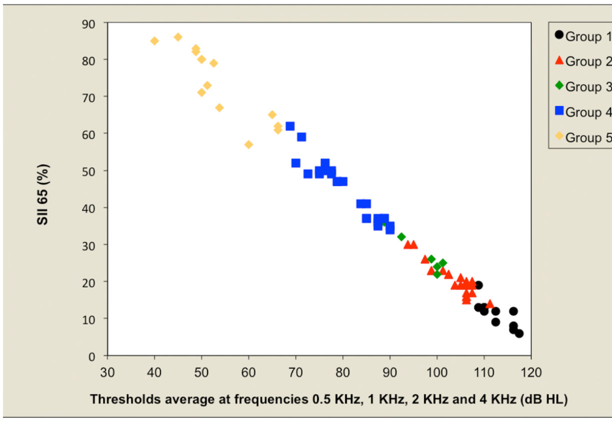

Figure 3. Scatter diagram of SII 65 values and hearing thresholds average at frequencies 0.5, 1, 2 and 4 kHz per group established by the technique of cluster analysis

Table 1. Summary of results obtained from regression model with adjustment SII 65 as dependent variable and the thresholds at different frequencies as explanatory variables

Step		Coefficient	Standard error	p	VIF	R^2	Changes in R^2
1	Constant	125.88	2.53	<0.001		0.945	0.945
	PT2kHz	-0.98	0.03	<0.001	1		
2	Constant	130.35	1.59	<0.001		0.980	0.035
	PT2kHz	-0.71	0.03	<0.001	3.0		
	PT0,5kHz	-0.36	0.03	<0.001	3.0		
3	Constant	131.53	1.37	<0.001		0.986	0.006
	PT2kHz	-0.42	0.06	<0.001	18.3		
	PT0,5kHz	-0.40	0.03	<0.001	3.2		
	PT4kHz	-0.27	0.05	<0.001	13.5		
4	Constant	130.77	1.35	<0.001		0.987	0.001
	PT2kHz	-0.33	0.07	<0.001	24.3		
	PT0,5kHz	-0.32	0.04	<0.001	6.9		
	PT4kHz	-0.28	0.05	<0.001	13.7		
	PT1kHz	-0.14	0.05	0.008	15.2		

hearing loss, for speech intelligibility, and not just the degree of hearing loss alone. Hence the reason for an alternatively classification in the factors considered as parameters in the validation process.

Determining SII 65 ranges to guide expectations of performance on the auditory skills observation related to audibility of speech sounds

Given the heterogeneity found in the SII 65 values - even though the ears were classified according to similar audiological features - this study aimed to establish ranges of SII 65 values to guide the clinician regarding the suitability of amplification and prognosis for audibility of speech sounds.

It can be observed from the analysis that the SII 65 value of 35% separates the Gr1, Gr2 and Gr3 from the other groups and that a value close to 60% seems to be appropriate to separate the Gr4 and Gr5 (Figure 3).

Sensitivity and specificity were calculated to formally determine the value that maximizes both the percentages of correct classification in Gr4 and Gr5 and determine a cutoff value of SII 65 between these two groups. From these values, it was possible to establish the cutoff value of 55%, associated to the value corresponding to higher values of specificity and sensitivity.

The value corresponding to higher probability of correct classification in both groups point is represented by a square. This point corresponds to the SII 65 cutoff value at 55%. The area under the curve is 0.99. The higher than 0.5 this value is, the better the SII 65 separates the two groups, which confirms the good discriminatory power of the SII 65. Estimates of the probabilities of correct classification in the two groups corresponding to the cutoff values are: 0.92 for the Gr4 and 1.00 for Gr5. Thus, the SII 65 values can be divided into three intervals (Int_{SII}): $Int_{SII\leq35}$ - 0 to 35%; $Int_{SII36\text{-}55}$ - 36-55%; and $Int_{SII\geq56}$ - 56-100%.

Table 3 was constructed from the three intervals determined. It shows the frequencies and percentages of SII 65 categorized in each group.

Note that of the 24 ears of Gr4 (composed of 13 ears with severe and 11 ears with profound hearing loss), only three were classified outside $Int_{SII36\text{-}55}$, which makes the group heterogeneous regarding the values of SII 65.

Table 3 also shows the relationship between the classification of the degree of hearing loss according to WHO and the intervals of SII 65 determined by the analysis.

Table 2. Descriptive statistics for SII 65 values per group established by the technique of cluster analysis and per degree of hearing loss (WHO)[23] (n=78)

	n	Average	Standard Deviation	Minimum	Median	Maximum
Groups						
Gr1	11	11.82	3.64	6	12	19
Gr2	22	20.45	4.27	14	19.5	30
Gr3	7	28.86	6.07	22	26	37
Gr4	24	44.58	7.99	34	47	62
Gr5	14	73.64	9.79	57	76	86
Degree						
Moderate	11	76.64	8.82	57	80	86
Severe	16	53.18	6.27	47	50	65
Profound	51	23.2	9.83	6	22	41

Table 3. Frequencies and percentages of SII 65 intervals (Int_{SII}) distributions, categorized by group and by degree of hearing loss (n=78)

	Intervals						Total	
	$Int_{SII\leq35}$		$Int_{SII36\text{-}55}$		$Int_{SII\geq56}$			
Groups	n	%	n	%	n	%	n	%
Gr1	11	100	0	0	0	0	11	14.1
Gr2	22	100	0	0	0	0	22	28.2
Gr3	5	71.4	2	28.6	0	0	7	9
Gr4	1	4.2	21	87.4	2	8.4	24	30.7
Gr5	0	0	0	0	14	100	14	18
Total	39	50	23	29.5	16	20.5	78	100
Degree								
Moderate	0	0	0	0	11	100	11	14.1
Severe	0	0	11	68.7	5	31.3	16	20.5
Profound	39	76.4	12	23.6	0	0	51	65.4
Total	39	50	23	29.5	16	20.5	78	100

DISCUSSION

Children undergoing language development have different acoustical needs compared to adults and older children. All acoustic information of speech is of utmost importance for the development of auditory and linguistic skills. The Speech Intelligibility Index (SII) is a measure used at the Audiology clinic for reflecting the likely potential of hearing use and for assisting the clinician in the guidance on the impact of hearing loss on language development, whereas there are factors unique to each child.

The purpose of this study was to analyze comparatively the SII 65 values obtained during the verification of hearing aids according to the DSL*m*[i/o] v5 prescription and to propose a classification of individuals that considers the association of the variables degree and configuration of hearing loss.

Cluster analysis, with the composition of five homogeneous groups regarding characteristics of hearing loss, allowed studying and verifying the behavior of SII 65 values for different combinations of thresholds and configuration of hearing loss.

As in other studies(12-14,24) SII 65 values strongly correlated with the mean auditory thresholds. The correlation is always negative, indicating that as the average of thresholds increases, i.e. the degree of hearing loss increases, the SII 65 value decreases, indicating less audibility and intelligibility. Despite the differences between the studies cited above regarding which frequencies were used to calculate averages for correlation with SII 65, there is always a strong correlation.

All frequencies are important for speech intelligibility. The frequency 2000 Hz, when correlated separately with the values of SII 65, has the highest value of r, indicating that this is often the largest contributor to the behavior of the SII 65 variation. Invariably, the studies cited include frequency 2000 Hz in the mean calculation. Furthermore, according to the ANSI S3.5-1997(10) parameters, when using the method of third octave frequency, the frequency band number 12, which is equivalent to the frequency 2000 Hz, has the highest ratio of importance (0.0898) relative to the other 17 bands included in the calculation.

The SII 65 value decreases to ears of the same group with the same degree and descending audiometric configuration.

The ear with the lowest value of SII 65 in Gr5 (57%) has a sloping ramp audiometric configuration with a difference of 55 dB between the thresholds at 1000 Hz (30 dB) and 2000 Hz (85 dB). The SII 65 values higher than 57% are from ears with auditory thresholds up to 75 dB at the frequency of 2000 Hz. However, the ears with a threshold higher than 80 dB HL at the frequency of 2000 Hz have SII 65 values up to 50%.

The literature(13) points out that SII values below 35% do not favor the development of canonical babbling, that is, an intelligibility of up to 35% is not sufficient for the development of speech production of consonants. The study mentions the need for an essential and minimum level of intelligibility for the development of babbling.

In the present study, 39 ears (50%) had SII 65 values below 35%, and the group of ears studied had predominantly mean hearing thresholds that were higher than 80 dB HL, configuring a group of 65.4% (51 ears) with profound hearing loss according to the WHO(23) classification.

According to the cluster analysis, the 39 ears were divided among Gr1, Gr2 and Gr3, characterized by profound hearing loss with differences in audiometric configuration. Children with these hearing characteristics are those whose families, early in the hearing aid selection process, should be guided regarding the limitations of amplification, environment and the distance between the sound source and the microphone of hearing aids, educational approaches and other technologies available (cochlear implants). SII can and should be used as a guidance tool for families of children with hearing impairment(3,9,12). The understanding of the family in relation to hearing impairment and the importance of treatment is the decisive factor for the consistent use of amplification - a key variable for child development(25,26).

Children with auditory characteristics similar to those of Gr4 and Gr5 have great variability in the SII 65 values according to the DSL*m* [i/o] v5, despite the homogeneity of audiological features. The adequacy of the target output amplification is determinant of the intelligibility factor and a precondition for the development of auditory and language skills when dealing with children without other disabilities.

Therefore, knowing measures that assess the adequacy of pediatric amplification in the Audiology clinic is of fundamental importance to the therapeutic process aiming at the development of oral language.

This study allowed determining two equations for evaluating the appropriateness of amplification through audiometric characterization and analysis of variation of SII 65 in terms frequencies.

The first equation, result of the discriminant analysis, allows the Audiologist to determine in which group of audiological features of the patient fits and to analyze what range of SII 65 (Int_{SII}) is expected from amplification for the patient. The prediction of the SII 65 soon after the diagnosis without first having initiated the selection process itself can be of great value to start the guidelines and facilitate the understanding of the family in relation to the hearing of the child.

The second equation, resulting from the analysis of which frequencies have a stronger contribution to the SII 65, allows the calculation of the adjusted SII 65 value that is expected from amplification in each case. This calculation considers the two frequencies that together predict an appropriate SII 65 value: the frequencies of 500 and 2000 Hz.

This equation, which adjusts the SII 65 value, considers the same minimum frequencies of diagnostic pediatric audiology protocols(4), because as they together predict audiological configuration they allow the beginning of the intervention process with the selection and fitting of hearing aids on babies under six months of age, until they are able for visual reinforcement audiometry.

The ANSI S3.5-1997(10) provides the parameters for calculations of SII 65 for listeners and hearing impaired individuals, considering interferences as noise and speech material. Such calculations can be performed with the aid of a software and require data that go beyond the auditory threshold of the patient, which makes it impractical to use it in pediatric clinical practice.

The current study aimed to analyze the relationship between the SII 65 values generated during the HA verification in patients with different degrees and configurations of hearing loss, and generated simple equations that can be used in the Audiology clinic to assess the adequacy of amplification, guide expectations of intelligibility in situations of silence, instruct families about hearing and amplification and guide clinical decisions regarding treatment and audiological approach to each case. When there is no compatibility between expected audibility capacity and performance in validation procedures, speech pathologists could refer to verification and/or adjustments of hearing aids, confirmation of thresholds or consider other disabilities. Such equations do not replace the verification procedure of amplification devices. It is during the HA verification that the audiologist will obtain the real value of SII 65 and evaluate the desired targets according to the DSL*m* [i/o] v5 method- and not according to the software provided by manufacturers of hearing aids, as evidenced by studies[7,8,27,28].

CONCLUSIONS

- Cluster analysis of the ears allowed a classification of hearing loss that aimed to consider variables associated to degree and configuration. It resulted in five heterogeneous groups among each other and with within-group homogeneous auditory characteristics regarding auditory thresholds. This proposed classification by groups seems to have more sensitivity to discriminate individuals concerning audiological characteristics as compared with the traditional WHO classification. The analysis of the relations between the values of SII 65 and the classification of hearing loss according to group, and the classification according to degree of hearing loss (WHO), showed that the proposed classification by groups seems to have more sensitivity for predicting the speech intelligibility index (SII).
- Equations were generated from statistical models used for cluster analysis of the ears studied. The equations allow the classification of a new ear (individual) in the groups proposed for classification of hearing loss. The use of the equations assumes that the acoustic characteristics of the hearing aids hit the target in the prescriptive rule, a result of the verification process, essential in each case.
- The combination of frequencies 2000 Hz and 500 Hz contribute to predict the SII 65 values for each ear (individual). An equation was generated for obtaining the SII 65 value, adjusted from the hearing thresholds in the 500 and 2000 Hz frequency.
- Three intervals of SII 65 were obtained to assist the clinician in assessing the suitability of amplification in the pediatric population. The first consists of SII 65 values below 35% ($Int_{SII \leq 35}$) and addresses hearing loss of Gr1, Gr2 and Gr3; the second range is formed by SII 65 values between 36 and 55% ($Int_{SII36\text{-}55}$) comprising Gr4; the third interval is composed by SII 65 values higher than 55% ($Int_{SII \geq 56}$) composed by ears of Gr5.
- The appreciation of SII 65 value obtained in the verification process, and their use in classification proposed here, can be a guide to expectations of parents and speech therapists involved in rehabilitation. If the auditory behavior are not consistent with the expected audibility of speech during the validation process other variables must be considered. Others disabilities should be considered or, eventually, thresholds might have changed or there could have been lack of verification during programming of hearing aids leading to performance not equivalent to estimated intelligibility.

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Author contributions

RSLF Research Project planning (doctorate degree): bibliographical and methodological study, collection and analysis of data. Production and reviewing; BM Research Project evaluation. Final text review; MCVC Data collection. Review the final text; BN Supervisor of the research project that lead to this article: methodological study, data analysis. Production and reviewing the final text.