Original Article

https://doi.org/10.1590/2317-6431-2016-1733

Audiology Communication Research
ISSN 2317-6431

Speech Intelligibility Index (SII) and variation of speech signal intensity in hearing impaired children

Índice de inteligibilidade (SII) e variação da intensidade do sinal de fala em crianças com deficiência de audição

Renata de Souza Lima Figueiredo[1], Beatriz Mendes[1], Maria Carolina Versolatto Cavanaugh[1], Tatiana Medeiros Deperon[1], Beatriz Novaes[1]

ABSTRACT

Purpose: To compare aided speech intelligibility index (SII) values in different speech signal inputs (75, 65, and 55 dBNPS), generated from the verification process of hearing aids, under different hearing loss severities and configurations. **Methods:** 41 children aged between three and 80 months old were selected, totalizing 78 ears (after exclusion of four ears). Hearing loss was classified according to audibility groups and SII intervals. Two hundred and thirty-four (234) SII values were analyzed as per speech stimulus and with regard to groups and audibility intervals. **Results:** Movement of audibility groups along SII intervals was observed, which indicates variation associated with the input signal intensity, as well as with the distance between the sound source and the hearing aid microphone. Two equations were generated to predict SII values from input signal SII65. **Conclusion:** Lower levels of speech stimulus sound pressure produce lower levels of speech intelligibility. This difference is more pronounced in hearing-impaired persons, who present SII values between 36 and 55%.

Keywords: Speech intelligibility; Hearing aids; Hearing loss; Children; Rehabilitation of hearing-impaired persons

RESUMO

Objetivo: Comparar valores do índice de inteligibilidade de fala amplificado, para diferentes entradas de sinal de fala (75, 65 e 55 dBNPS), gerados no processo de verificação dos aparelhos de amplificação sonora, nos diferentes graus e configurações de perdas auditiva. **Métodos:** Foram selecionadas 41 crianças com idades entre 3 e 80 meses, totalizando 78 orelhas (quatro orelhas foram excluídas). As perdas auditivas foram classificadas conforme grupos de audibilidade e intervalos do índice de inteligibilidade de fala. Foram analisados 234 valores do índice de inteligibilidade de fala para os estímulos de fala e estes foram também analisados, em relação aos grupos e intervalos de audibilidade. **Resultados:** Os grupos de audibilidade se deslocaram entre os intervalos do índice de inteligibilidade de fala, indicando a variação, conforme o nível de apresentação do sinal de entrada. Duas equações foram geradas para prever valores do índice de inteligibilidade de fala a partir do valor deste índice para o sinal de entrada de 65. **Conclusão:** Menores níveis de pressão sonora do estímulo de fala produzem menores índices de inteligibilidade de fala. Esta diferença é mais acentuada nos deficientes auditivos, que apresentam valores do índice de inteligibilidade de fala de 65 entre 36% e 55%.

Palavras-chave: Inteligibilidade de fala; Auxiliares de audição; Perda auditiva; Criança; Reabilitação de deficientes auditivos

Study carried out at Centro Audição na Criança – CeAC, Divisão de Educação e Reabilitação dos Distúrbios da Comunicação – DERDIC, Pontifícia Universidade Católica de São Paulo – PUC-SP – São Paulo (SP), Brasil.
[1]Pontifícia Universidade Católica de São Paulo – PUC-SP – São Paulo (SP), Brasil.
Conflict of interests: No.
Authors' contribution: RSLF doctoral research project elaboration: bibliographical and methodological study, data collection and analysis, elaboration and review of the final text; BM research project evaluation, review of the final text; MCVC data collection, review of the final text; TMD data collection, review of the final text; BN advised the research project from which this article is derived: methodological study, data analysis; elaboration and review of the final text.
Funding: This study is derived from a doctoral thesis financed by CAPES – PROSUP.
Corresponding author: Renata de Souza Lima Figueiredo. E-mail: rsl.figueiredo@gmail.com
Received: July 20, 2016; **Accepted:** May 21, 2018

INTRODUCTION

Over the last decade, research has found positive results in speech and language development from early intervention programs aimed at hearing-impaired infants when the intervention takes place from their first year of life. These surveys have confirmed the importance of fitting amplification to ensure audibility of speech sounds as one of the conditions required for speech development in hearing-impaired children[1-6].

The Speech Intelligibility Index (SII) value is highly correlated with speech intelligibility under adverse hearing conditions, such as auditory masking, filters, and reverberation[7].

In the field of Audiology, this value is used as a measure to evaluate the audibility of the speech signal in the selection process during electroacoustic testing of hearing aids (or personal sound amplification products) as an auxiliary tool in speech stimulus target output verification at different levels of sound pressure. It is also used as a strategy for family guidance and as a measure to predict the audibility of speech sounds in different sound environments[8].

Making all sounds audible may not ensure their discrimination. The discrimination capacity involves many factors and, in individuals with hearing loss, besides changes in the neural processing of signals, the hearing aids themselves may cause distortions that hinder or even preclude discrimination of a speech signal[9].

Besides the factors inherent to hearing loss, external factors may interfere in the audibility of speech sounds by hindering the integrity of the acoustic signal: distance, noise, and reverberation. Therefore, environmental conditions must also be taken into account when dealing with hearing-impaired infants and children.

Access to speech sounds in different situations (distances and environments) is important for children, as their learning is largely a consequence of "incidental listening"[10].

Distance changes the "volume" of the voice. Whenever distance is involved, the listener's sound source is doubled, and voice intensity drops by 6 dB. This relation between distance and speech signal intensity is known as the "6 dB rule"[11].

Thus, distance is a condition for audibility. This becomes crucial as infants grow, since motor development naturally allows children to gradually distance themselves from the speaker. Thus, the speech-language therapist must guide families as to the distance at which the child has enough audibility to allow for learning.

Consequently, studying the variation of speech signal intensity and audibility, aiming to guide the family as well as clinical and therapeutic management, from the very beginning of the intervention process proves important for language development in children.

This study aimed to conduct a comparative analysis of the SII values amplified for the different speech input signals of 75, 65, and 55 dBNPS generated in the verification process of the adjusted hearing aids in accordance with the Desired Sensation Level (DSL) v5.0 rule at the various levels and configurations of sensorineural hearing loss. The findings also aimed to relate audibility and distance to guide the therapeutic intervention process and the clinical and therapeutic decisions from the first months of amplification use.

METHODS

Research location and ethical guidelines

This study was carried out at the Child Hearing Center (Centro Audição na Criança – CeAC), linked to the Division of Education and Rehabilitation for Communication Disorders of Pontifícia Universidade Católica de São Paulo – DERDIC/PUC-SP, as well as to the Post-Graduation Program in Speech-Language Therapy/Child Hearing of Pontifícia Universidade Católica de São Paulo – PUC-SP. As part of a wider study project on the sound amplification verification and validation process in hearing-impaired children, this study complies with the rules set out by the code of human research ethics and has been approved by the PUC-SP Human Research Ethics Committee, as per protocol nº 337/2010.

Research individuals

Inclusion criteria

Forty-one patients aged between 4 and 80 months, who have been diagnosed with sensorineural hearing loss across different severities and configurations and who participated in the selection process of hearing aids throughout 2011 were selected, totalizing 82 ears. Of these, two ears of cochlear implant (CI) users were excluded, as well as two ears of children with anacusis - thus, 78 ears were available for analysis. Non-linear hearing aids were prescribed to all children.

Hearing loss classification

The ears were classified into groups and SII65 intervals[12]. A classification was proposed considering the dynamics of the relationship between hearing impairment severity and configuration. Chart 1 summarizes the result of the hearing loss classification into five groups.

Procedures

Definition of hearing thresholds for analysis

The hearing threshold*s* used to program (LP) the devices were determined based on the audiological evaluation in accordance with the protocol set out by the institution's staff. The dBNA (LP) threshold was used for the analysis in the 250, 500, 1000, 2000 and 4000 Hz frequencies. When response to these frequencies was not observed, up to the devices' threshold, the value considered was that registered in the Noah® software for hearing aid programming.

Chart 1. Classification of hearing impairment per group and SII65 intervals, according to Figueiredo et al.[12]

Groups	Audiological characteristics	SII65 intervals (Int_{SII})
G1	Profound hearing loss/horizontal configurations	$Int_{SII \leq 35}$ SII65 up to 35%
G2	Profound hearing loss / mild descending configurations	
G3	Profound hearing loss / sharp or sloping descending configurations	
G4	Severe and profound hearing loss up to 90 dBNA/ horizontal and mild descending configurations	$Int_{SII36-55}$ SII65 from 36 to 55%
G5	Severe and profound hearing loss up to 66 dBNA/ horizontal and mild descending configurations	$Int_{SII \geq 56}$ SII65 above 55%

Subtitle: SII = *Speech Intelligibility Index*; Int_{SII} = Speech Intelligibility Index interval; G = Group

Obtaining SII values

The hearing aids were selected and programmed from the threshold values established in the diagnostic process in accordance with the DSL v5.0 rule. Real ear to coupler difference (RECD) measurements were taken with the earmolds. When this was impossible, the values predicted by the aforementioned rule were used.

Considering the auditory thresholds and RECD (measured or estimated), the hearing aids were programmed by means of the proprietary software of the devices' manufacturers. Resources such as frequency compression or frequency transposition, when available for the hearing aid model, were deactivated. In the case of other resources, such as noise reducer, directionality, and expansion, the manufacturer's recommendations were applied to the verification mode suitable for each model.

Verification measurements for 55, 65, and 75 dBNPS speech sounds and maximum power output - MPO (90 dBNPS) were carried out on Verifit®Audioscan.

For the coupler or *in situ* verification measurements based on the hearing aids' response curves, according to the frequencies obtained from a speech input signal, the equipment calculates SII values in percentages, considering a 65 dBNPS input with no amplification and for different speech stimulation inputs with amplification, at the pressure sound levels of 40 to 75 dB. The equipment performs calculations as per the 1/3 octave frequency method, described by the American National Standards Institute (ANSI S3.5-1997), without taking into account the 160 Hz frequency range and without auditory masking, i.e. the equipment calculates SII for an ideal hearing environment. To calculate SII, Verifit®Audioscan considers the dynamic area of speech stimulus and the distortion effects related to the intensity of the input signal.

SII values are represented on a scale from zero to 100%, where zero indicates no audibility, and 100, audibility of all sounds of speech.

The stimuli used to check the hearing aids were Standard-speech (Speech-std 1) and "carrot passage" pure-tone screening (maximum output - MPO).

To determine similar values between the electroacoustic features of gain and output, prescribed in the DSL v5.0 software, and the values found in the hearing aids, a difference of more or less 3 dB was used[13].

SII values were analyzed for 75, 65, and 55 dBNPS speech stimulus, henceforth named as SII75, SII65 and SII55, respectively.

Thus, in the hearing aids verification process, three SII values were obtained for each ear - a total of 234 SII values.

Data analysis

The SII75, SII65 and SII55 values were compared to analyze the effects of distance on speech intelligibility indexes. For this purpose, a 75 dBNPS input signal may be considered as a sound source near the hearing aid microphone; a 65 dBNPS input signal is considered as a conversational distance, and a 55 dBNPS input may represent longer distances starting from two meters between the speaker and the hearing aid microphone.

Analysis of the behavior of SII75, SII65, and SII55 values in relation to the groups and SII65 intervals (Int_{SII})

From the classification of ears according to SII65 groups and intervals suggested by Figueiredo et al.[12], the behavior of SII values was analyzed in aggregate according to the change in the sound pressure level of the input signal (75, 65, and 55 dBNPS).

Analysis of the relations between SII75 and SII65, and between SII55 and SII65

In order to study the relation of the differences between SII55 and SII65, and between SII75 and SII65, regression models were adjusted. The expressions of the difference between the two SII analyzed were derived from these models, whereas the values of SII65, whose differences are maximum, were determined with the objective of analyzing the SII variation upon increase and decrease of the input signal.

The averages of the differences between SII75 and SII65 and between SII55 and SII65 were compared for the five groups of ears. The differences between the averages were found by means of the Tukey method[14]. Ears with equal estimated averages were grouped together, and confidence intervals were set at 95% for the average differences.

A 0.05% significance level was adopted for hypothesis testing.

RESULTS

Analysis of the behavior of SII75, SII65, and SII55 values in relation to SII groups and intervals (Int_{SII})

The joint performance of the SII75, SII65, and SII55 values in relation to the average of 500, 1000, 2000 and 4000 Hz frequencies is shown in the scatter plots in Figure 1. Horizontal

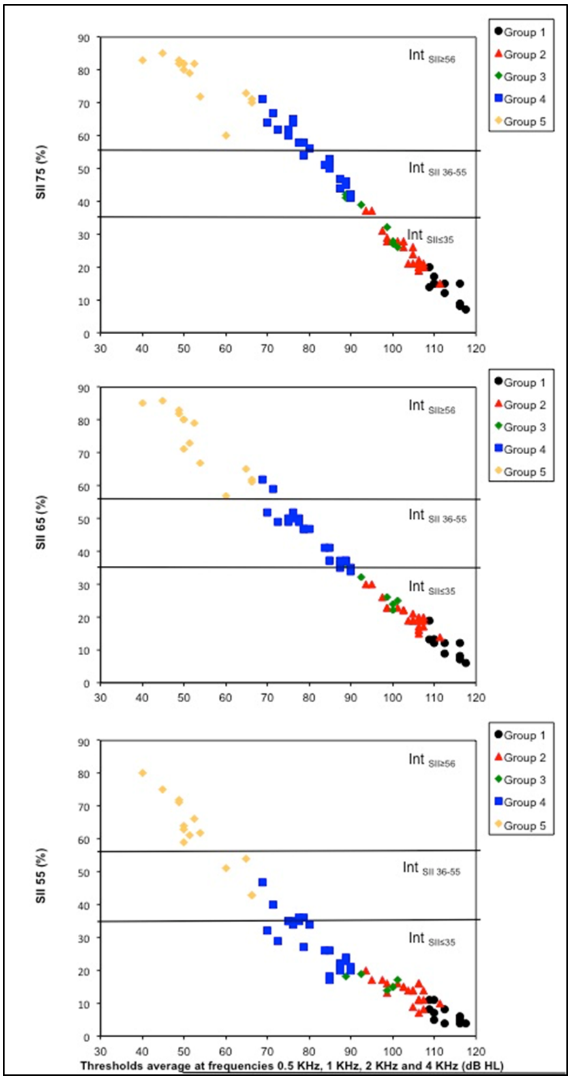

Figure 1. Scatter plot of the values of SII75, SII65, and SII55 and the average of thresholds in the frequencies of 500, 1000, 2000 and 4000 Hz (dBNA) and the intervals established based on the analysis of SII65
Subtitle: SII = Speech Intelligibility Index

lines were added to represent the intervals (Int_{SII}) established from the SII65 analyses (in accordance with Chart 1).

Movement of the groups along the set of intervals was observed, which demonstrates that variation of the input signal, or variation of the distance between the sound source and the hearing aid microphone, directly affected aided SII values, especially when the values generated from the 65 and 55 dBNPS input were compared. It was observed that the group which moved the most along intervals was Gr4, composed by children with severe and profound hearing loss according to the World Health Organization – WHO classification[15].

Most of the ears in Gr4 were grouped within the $Int_{SII36-55}$ interval for the values of SII65 and, when the level of the input signal was changed to 55 dBNPS, the majority of ears moved to interval $Int_{SII\leq35}$. On the other hand, approximately half of the group increased to the SII65 value interval above 56% ($Int_{SII\geq56}$), with the input signal increasing to 75 dBNPS.

The SII65 ears of Gr5 were found in interval $Int_{SII\geq56}$, no great movement was observed between the SII65 value intervals upon decrease of the input signal to 55 dBNPS. Only a few ears with SII65 values closer to 56% moved to interval $Int_{SII36-55}$. Therefore, Gr5 may be considered the group less affected by the change in input signal or in distance upon analysis of aided SII values.

It was also found that Gr1, Gr2, and Gr3 did not move between intervals upon decrease in input signal. They already presented low speech intelligibility levels for a 65 dBNPS signal. With an increase to 75 dB in sound pressure level, it was found that some ears in the Gr3 group reached SII values within interval $Int_{SII36-55}$.

Relations between SII75 and SII65 and between SII55 and SII65

The joint performance of SII75 and SII65 (A) and the joint performance of SII55 and SII65 (B) are shown in Figure 2.

The equation of the curve represented in Figure 2A, which relates the two variables (SII75 as response variable and SII65 as explanatory variable) is:

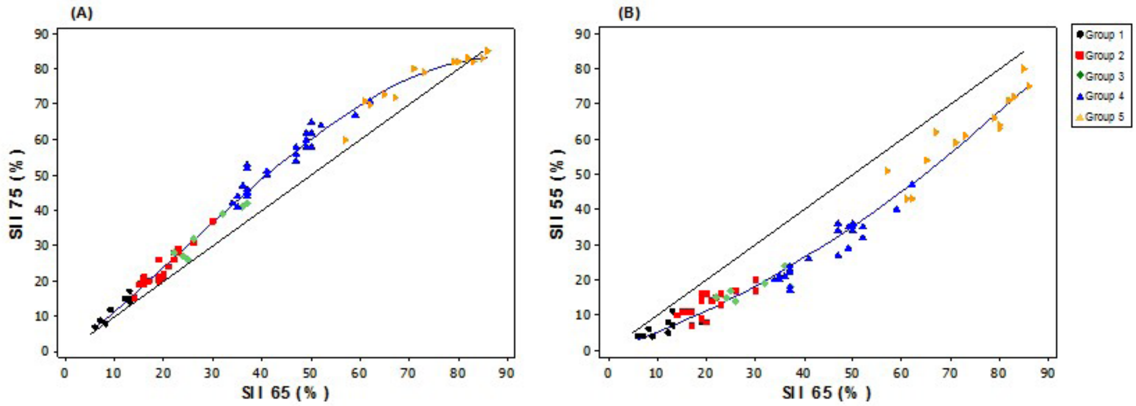

Figure 2. Scatter plots: (A) of SII75 and SII65 with fitted curve and straight line SII75 = SII65; and (B) of SII55 and SII65 with fitted curve and straight line SII55 = SII65
Subtitle: SII = Speech Intelligibility Index

$$Estimated\ SII75 = 0.1 \times SII65 + 0.007 \times SII65^2 - 0.0001 \times SII65^3 \quad (1)$$

That is, the relation between SII75 and SII65 is explained by a third degree polynomial. The value of SII65, for which the distance between the two SII (SII75 and SII65) is maximum, was obtained analytically, where a SII65 value equal to 53.3% was found.

The equation of the curve represented in Figure 2B, which relates the two variables (SII55 as response variable and SII65 as explanatory variable) is the following:

$$Estimated\ SII55 = 0.47 \times SII65 + 0.0047 \times SII65^2 \quad (2)$$

That is, the relation between SII55 and SII65 is explained by a parabola. It was found that the distance between both curves became greater with the increase of SII65 up to, approximately, the value of 55%, whereas it tended to decrease afterwards. The value of SII65, for which the distance is maximum, was obtained analytically, and a value of SII65 equal to 56.4% was found.

Descriptive statistic values for the differences between SII75 and SII65 values and between the SII55 and SII65 values in each group can be found in Table 1.

An analysis of variance was used to compare the average differences in the five groups for the relations between SII75 and SII65 and SII55 and SII65. A variation between the average differences in the five groups ($p<0.001$) was found. The Tukey method was then employed to find the differences between the five averages. The results obtained are summarized in Table 2.

Based on the abovementioned results, the groups with the same averages were put together, the average differences were re-estimated, and confidence intervals were drawn up for the average differences. The results obtained are presented in Table 3.

Table 1. Statistical description of the differences between SII75 and SII65 (SII75-SII65) and between SII55 and SII65 (SI65-SII55) in the five groups (n=78)

	Group	n	Average	Standard deviation	Minimum	Median	Maximum
SII75-SII65	G1	11	2.1	1.2	0	2	4
	G2	22	3.8	2.1	1	3.5	7
	G3	7	4.7	2.1	1	5	7
	G4	24	10.2	2.7	6	9	16
	G5	14	3.8	3.9	-2	3	10
	Total (SII75 -SII55)	78	5.6	4.0	-2	5	16
SII65-SII55	G1	11	4.6	2.9	2	4	11
	G2	22	7.0	2.8	3	7	13
	G3	7	11.4	4.0	7	12	19
	G4	24	15.7	2.6	11	15	20
	G5	14	11.9	4.5	5	11.5	19
	Total (SII65-SII55)	78	10.6	5.2	2	11	20

Subtitle: SII = *Speech Intelligibility Index*; G = Group

Table 2. Results obtained comparing the average differences between SII75 and SII65 and between SII55 and SII65 in the five groups, two by two, Tukey's method

	Group (I)	Group (J)	Difference of averages (I-J)	Standard deviation	P value
SII75 and SII65	G1	G2	-1.7	0.96	0.414
		G3	-2.6	1.26	0.241
		G4	-8.1	0.95	<0.001
		G5	-1.7	1.05	0.496
	G2	G3	-0.9	1.13	0.920
		G4	-6.4	0.77	<0.001
		G5	0.0	0.89	1.000
	G3	G4	-5.5	1.12	<0.001
		G5	0.9	1.21	0.939
	G4	G5	6.4	0.88	<0.001
SII55 and SII65	G1	G2	-2.4	1.20	0.270
		G3	-6.8	1.57	<0.001
		G4	-11.1	1.18	<0.001
		G5	-7.3	1.31	<0.001
	G2	G3	-4.4	1.41	0.021
		G4	-8.7	0.96	<0.001
		G5	-4.9	1.11	<0.001
	G3	G4	-4.3	1.39	0.024
		G5	-0.5	1.50	0.997
	G4	G5	3.8	1.09	0.008

Subtitle: SII = *Speech Intelligibility Index*; G = Group

Table 3. Averages of the difference between SII75 and SII65 (SII75 - SII65) and between SII55 and SII65 (SII65-SII55) in the groups formed after the analysis of variance and confidence intervals of 95%

	Group	Average	n	Lower limit	Upper limit
SII75 and SII65	G1+G2+G3+G5	3.56	54	2.86	4.26
	G4	10.17	24	9.13	11.21
SII55 and SII65	G1+G2	6.24	33	5.13	7.35
	G3+G5	11.76	21	10.37	13.15
	G4	15.71	24	14.41	17.01

Subtitle: SII = *Speech Intelligibility Index*; G = Group

Table 4. Pearson correlation coefficients of the differences SII75 - SII65 and SII65 - SII55 and the hearing thresholds in 250, 500, 1000, 2000 and 4000 Hz (n=78)

		250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
SII75 - SII65	r	-0.15	-0.12	-0.19	-0.28	-0.30
	p	0.193	0.306	0.098	0.013	0.008
SII65 - SII55	r	-0.42	-0.42	-0.48	-0.59	-0.59
	p	<0.001	<0.001	<0.001	<0.001	<0.001

Subtitle: SII = *Speech Intelligibility Index*; r = Pearson correlation coefficient; p = level of significance

The Pearson correlation coefficient values of the difference SII75-SII65 and SII65-SII55 and the auditory thresholds at 250, 500, 1000, 2000 and 4000 Hz are presented in Table 4.

DISCUSSION

Knowing the audiological characteristics and the results of an adequate amplification has allowed us to study the audibility variability for sounds of different intensities.

A comparison of the SII values at the sound pressure values of 75, 65, and 55 dBNPS in relation to the three SII65 intervals found that, upon lowering the input signal from 65 to 55 dBNPS, most of the Gr4 ears - classified in the $Int_{SII36-55}$ interval - moved to the range of SII65 values under 35% ($Int_{SII\leq35}$), whereas, in Gr5, only those with SII65 values near the lower limit moved to a lower interval ($Int_{SII36-55}$). Gr1, Gr2, and Gr3, classified within the lower value range of SII65 ($Int_{SII\leq35}$), did not change intervals upon lowering of the input sound level.

This fact is related to the limitations of amplification inherent to the dynamic field of hearing - the range between auditory thresholds and discomfort thresholds. A dynamic field of approximately 45 dB is needed for auditory perception of changes in intensity of the acoustic components of the speech signal[16].

In dynamic hearing situations under 45 dB, between the minimum audibility thresholds and the upper discomfort thresholds, it is not possible to "accommodate" all levels of speech signal - from weak to strong - so that children are able to perceive and identify the differences of acoustic signals. Children with audiological characteristics such as those of Gr1, Gr2, and Gr3 stand for the cases with very narrow dynamic field. Therefore, changes were not observed in the SII intervals with the increase or decrease of the input signal as, for a conversational input signal of 65 dBNPS, the SII values obtained are within the range of up to 35%.

For the cases with the audiological characteristics of Gr5, changes in the interval of SII values were also not observed upon input signal change, although for the opposite reason of groups Gr1, Gr2 and Gr3. Gr5 is the ear group with moderate hearing loss - thus, it had audiograms with dynamic field capable of "accommodating" sounds of weak to strong intensities, allowing for the perception of the changes in the sound pressure level of the input signal. Children whose hearing impairments characteristics similar to Gr5's and with audibility expressed by SII values above 55% have access to all speech sounds, even within the weakest levels of sound pressure (55 dBNPS).

On the other hand, the children in Gr4 - with average thresholds up to 90 dBNA - were the most affected by the changes in the input signal level, as the dynamic field is narrow, or just enough, to "accommodate" the different acoustic signal levels. This, consequently, leads to a great loss in terms of speech audibility with the decrease in the input signal, going from a SII interval of 36% to 55%, for values under 35% ($Int_{SII\leq35\%}$).

Thus, children with audiological characteristics such as those of Gr1, Gr2, and Gr3 require referral for IC (cochlear implant) indication early in the intervention process, affording proper audibility for the development of oral language. In children with the characteristics of Gr4, audibility is vulnerable, i.e. external factors such as distance and noise may interfere to the point in which low-intensity speech sounds are not perceived or identified by the child. The decrease in speech signal sound pressure level undermines access to the acoustic signal in several learning situations.

Considering the 6-dB Rule[11] - which states that when the distance between the sound source and the listener is doubled, the intensity of the sound decreases by 6 dB - distance is a factor that may interfere in the development of speech, as it changes access to speech sounds.

Hearing at a distance is related to incidental learning[10]. Children learn most of their oral language indirectly, when conversation is not directed at them. Access to conversations takes place remotely, when the child is not paying direct attention to them. Thus, any degree of hearing loss is a barrier to the child's ability to receive information from their environment.

In the analyses comparing SII values and the value intervals based on the audiological characteristics of the ears studied, it was observed that infants and children with hearing loss such as those in Gr4 are those that lose the most in terms of audibility, as expressed in SII65 values, with the decrease of the input signal, and that, for infants and children with hearing impairment such as those in Gr1, Gr2, and Gr3, amplification restricts access to all speech signals.

Thus, from the very beginning of the speech therapy intervention process, in the selection and prescription of sound amplification products, the speech-language therapist should be aware of the limitations of amplification in each case and guide families accordingly and with respect to the precautions regarding distance and other factors that may also interfere with the audibility of speech sounds.

In the comparative analyses between the aided SII values resulting from speech stimuli at 75 and 65 dBNPS, the greatest differences between SII values were found for the SII65 values of 53.3%. That is, upon verifying the hearing aids, when values of approximately 53.3% for SII65 are found, it is certain that the increase in sound pressure of the input signal will result in a greater increase in speech sounds audibility. Additionally, as the value of SII65 increases, the difference between SII75 and SII65 tends to gradually decrease, until, for SII65 values of nearly 80%, a minimum - or even negative - difference is observed between these values. Therefore, the increase in speech signal level for subjects whose audibility is expressed by SII65 values near 80% (hearing impairment with characteristics of Gr5, with SII interval $Int_{SII\geq 56}$) does not imply an improvement in the audibility of speech sounds.

People with sensorineural hearing loss, in any degree and configuration, present a reduced dynamic field of hearing so that, unlike people with normal hearing, the increase in the intensity sensation is not linear. Thus, increasing the sound pressure level does not necessarily imply an increase in speech audibility and intelligibility[17].

The ANSI[7] has referred to limitations in the calculation of the speech intelligibility index in hearing impaired individuals. Although the auditory threshold is one of the variables used for calculation of SII, the scope of the SII rule is limited to individuals with normal hearing. Hearing pathologies can have effects on speech intelligibility beyond what is anticipated by the auditory thresholds.

The analysis of variance used to compare the averages of the differences between the values of SII75 and SII65, in the five groups, has shown that Gr4, with SII65 values within the 36% to 55% interval ($Int_{SII36-55}$), presented the highest average of differences. This implies that the audibility of children with these audiological characteristics benefits from the increase in input signal intensity, or from the reduction of the distance between the sound source and the hearing aid microphone. However, the same does not apply to Gr1, Gr2, and Gr3, whose auditory dynamic field was much reduced in all frequency ranges (Gr1 and Gr2), or in some frequency ranges (sharp or sloping descending audiometric curves, as those in Gr3).

The correlation of the differences between the values of SII75 and SII65 and the auditory thresholds studied (250, 500, 1000, 2000 and 4000 Hz) were found to be negative for all frequencies, especially those of 2000 and 4000 Hz. Thus, as the auditory thresholds increase (higher hearing losses), the differences between the values of SII75 and SII65 decrease, particularly in the 2000 and 4000 Hz frequencies, indicating the need to consider both configuration and severity of hearing loss jointly in the evaluation of speech intelligibility indexes.

These findings are in line with other studies[18-21], which measured the intelligibility of amplified speech in certain frequency ranges and showed that the increase of gain for the higher frequencies is beneficial for speech recognition in hearing impairment cases with thresholds up to 60-80 dBNA. For hearing losses worse than 80 dBNA, the increase in the intensity of high frequencies implied, in some cases, a worsening of speech intelligibility. Thus, these studies concluded that the values of SII for speech recognition in adults are less precise for hearing losses with a descending configuration and higher degrees of hearing impairment.

In the process of selection and indication of hearing aids for infants and children, these findings point to the need for caution in evaluating the audibility expressed by SII values as, in hearing impairment cases with a descending configuration, the speech intelligibility index does not seem to accurately represent the expected result in terms of speech recognition[22].

The same comparative analyses carried out between the values of SII75 and SII65 were also undertaken between the values of SII55 and SII65. From these analyses, it was concluded that, as the values of SII65 increased, the difference between the values of SII55 and SII65 also rose until an approximate SII65 value of 56.4%. Above that, the difference tended to decrease, indicating that, for children with audibility expressed by SII65 values in the 36% to 55% interval ($Int_{SII36-55}$), the decrease of the input signal to 55 dBNPS implies a reduction of SII values to the interval of values of up to 35% ($Int_{SII\leq 35}$), making for a decrease in audibility for all speech sounds.

A study investigated the relation between the development of canonic babbling and audibility and corroborated that a value of SII equal or lower than 35% impedes the appearance of consonant production in infants' babbling[23]. Thus, children with SII65 values in the $Int_{SII36-55}$ interval have their access to speech sounds impaired as the intensity of the input signal decreases.

The averages of the differences between the values of SII55 and SII65 showed that, for the Gr1 and Gr2 groups (lower averages), the decrease in the input signal may not entail impairment of audibility, as, in these cases, amplification allows limited access to speech sounds, even in conversational intensity (65 dBNPS), and these are the cases in which CI (cochlear implants) should be prescribed.

The averages of the differences of Gr3 and Gr5, although higher than the averages of Gr1 and Gr2, were similar. Therefore, they have been grouped so as to indicate that children with these audiological characteristics tend to lose audibility with the decrease in the input signal intensity, but it is necessary to evaluate the characteristics of the hearing impairment.

As mentioned, in the differences between the values of SII75 and SII65, hearing losses with sharply descending, or sloping (Gr3), configuration may not be represented by the values of SII with regard to audibility and speech intelligibility. In the correlation analysis between the differences of SII55 and SII65 and the auditory thresholds in the frequencies studied, it was found that all frequencies presented a strong correlation with the differences, with higher coefficients for the 2000 and 4000 Hz frequencies, once again indicating the importance of the configuration of hearing impairment for the speech intelligibility indexes.

The hearing losses in Gr5 were those with values of SII65 in the $Int_{SII\geq 56}$ interval. The analysis of the differences for the intensity of 55 dBNPS pointed that, starting from a SII65 value of approximately 56.4%, the differences tended to decrease, which indicates that, for children with audibility above or equal to 56%, the better the audibility for the intensity of 65 dBNPS, the lower the loss when the intensity of the speech signal decreases.

The comparative analyses between the SII75-SII65 and SII55-SII65 values also generated two equations that allow the speech-language therapist to predict, from the value of SII65, the audibility of the 55 dBNPS and 75 dBNPS input signal for each case, and thus guide families with respect to the effects of the input signal intensity on children's audibility and on speech development. These equations can be very useful during the process of speech-language therapy intervention for the family's understanding of the child's hearing.

In their early development stages, infants are held in their parent's arms, which facilitates their access to speech sounds - as the distance to the mother or anyone who speaks to them does not hinder signal intensity. However, when the child begins to crawl and, later, to walk, this distance increases, and most of the speech signal is lost. At this stage, hearing loss becomes evident, since the absence of response to low-intensity sounds reflects on speech and language development. The first words may come about, but the mismatch between speech and language development and chronological age shows parents the disadvantages of not using hearing aids.

In this sense, the SII can be used to explain and illustrate infants' hearing impairment at the beginning of the process of selection and prescription of hearing aids, so that parents can understand the consequences of hearing loss and the limitations of amplification for speech and language development in each case. In turn, this allows them to consistently adhere to the use of hearing aids from the first months of the speech-language therapy intervention process.

Using the audiogram with the traditional classification of hearing loss - mild or moderate severities - for parental guidance in hearing loss contributes to their consistent underestimation of the impact of hearing loss on their child's speech and language development[24], which demonstrates the importance of care and sensitivity on the part of the speech-language therapist in communicating the issues around hearing loss to parents.

Looking for guidance methods to aid the speech-language therapist in raising parents' awareness about the relationship between hearing and speech and language development is very valuable at the beginning of the therapeutic process and contributes toward their adherence to the use of hearing aids[25].

CONCLUSION

With the change in the input signal sound pressure level, SII values change and the individuals in the groups move along the intervals established from SII65. Lower sound pressure levels of the speech stimulus produce lower speech intelligibility indexes. This difference is greater in hearing-impaired persons, who present values of SII65 between 36% and 55%.

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