Dead regions of the cochlea and hearing aid performance in children

Zonas mortas na cóclea e desempenho com uso da amplificação sonora em crianças

Zonas muertas en la cóclea y el rendimiento con el uso de la amplificación del sonido en los niños

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Abstract

Objective: *To investigate the occurrence of cochlear dead regions in children with mild to severe sensorineural hearing loss, making use of hearing aids; to study the correlation between the presence of dead regions and the benefit obtained from using amplification.* ***Methods:*** *15 children with mild to severe sensorineural hearing loss, ranging from 7 to 12 years of age, making use of hearing aids, were evaluated. For the identification of dead regions, the TEN (Threshold Equalizing Noise) test was utilized. The PEACH (Parent's Evaluation of Aural/Oral Performance of Children) questionnaire was administered to the parents or guardians in order to assess the children's performance with amplification in real-world situations.* ***Results:*** *According to the responses obtained in the TEN test, it was found that, in 33% of the children, the results suggested the presence of dead regions in the cochlea at one or more of the frequencies tested; 33% were negative for cochlear dead regions; and, in 33%, the responses obtained in the TEN test were inconclusive. In the PEACH questionnaire, the group without evidence of dead regions (G1) had a better performance under both quiet and noisy conditions when compared to those children with evidence of dead regions (G2) and the inconclusive group (G3).* ***Conclusion:*** *The occurrence of children with sensorineural hearing loss and evidence of dead regions was 33% in the sample surveyed. Children with evidence of cochlear dead regions had a poorer performance in all daily-life situations when compared to children without evidence of dead regions or inconclusive results in the TEN test, thus showing poorer benefits from using sound amplification.*

Keywords: *Cochlea; Hearing Loss; Child; Hearing Disorders; Hearing Aids.*

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Resumo

Objetivo: *Investigar a presença de zonas mortas da cóclea em crianças com perda auditiva sensorioneural; verificar a correlação entre a presença de zonas mortas na cóclea e o desempenho obtido com o uso da amplificação sonora.* ***Método:*** *Foram avaliadas 15 crianças com perdas auditivas sensorioneurais de grau leve a severo, na faixa etária entre 7 e 12 anos, adaptadas com próteses auditivas. Para a identificação de zonas mortas na cóclea, aplicou-se o teste TEN (Threshold Equalizing Noise). Para verificar o desempenho da criança com amplificação nas situações do cotidiano o questionário PEACH (Parent´s Evaluation of Aural/Oral Performance of Children) foi aplicado aos seus responsáveis.* ***Resultados:*** *De acordo com as respostas obtidas no teste TEN, verificou-se em 33% das crianças apresentaram resultados sugestivos de presença de zonas mortas na cóclea em uma ou mais freqüências testadas; em 33% os resultados foram negativos para zonas mortas da cóclea e em 33% as respostas obtidas foram inconclusivas ao teste TEN. No questionário PEACH, o grupo sem indícios de zonas mortas (G1) obteve melhor desempenho, tanto em silêncio, quanto em ruído, em comparação aos grupos com indícios de zonas mortas (G2) e grupo inconclusivo (G3).* ***Conclusão:*** *A ocorrência de zonas mortas na cóclea foi de 33% na amostra pesquisada. Crianças com indícios de zonas mortas na cóclea apresentaram pior desempenho auditivo em todas as situações do cotidiano em comparação com crianças sem indícios de zonas mortas ou com resultados inconclusivos no teste TEN, demonstrando menor benefício com o uso da amplificação sonora.*

Palavras-chave: *Cóclea; Perda Auditiva; Criança; Transtornos da Audição; Auxiliares de Audição.*

Resumen

Objetivo: *Investigar la presencia de zonas muertas de la cóclea en niños con pérdida auditiva neurosensorial y comprobar su correlación con el rendimiento obtenido con el uso de la amplificación.* ***Métodos:*** *Se evaluaron 15 niños con pérdida auditiva neurosensorial de leve a severa, con edades comprendidas entre los 7 y 12, equipados con audífonos. Para la identificación de zonas muertas en la cóclea se aplica la prueba TEN (Threshold Equalizing Noise). Para comprobar el rendimiento de la amplificación en situaciones cotidianas, el cuestionario PEACH fue administrado a los padres.* ***Resultados:*** *De acuerdo con las respuestas obtenidas en la TEN, se encontró en el 33% de los niños los resultados sugieren la presencia de zonas muertas en la cóclea en una o más frecuencias probadas; 33% de los resultados fueron negativos para las zonas muertas de la cóclea y en el 33% de las respuestas fueron poco concluyentes de la prueba TEN. En el cuestionario PEACH, el grupo sin zonas muertas (G1) obtenido mejores resultados, tanto en el silencio y el ruido en comparación con el grupo con zonas muertas (G2) y el grupo poco concluyentes (G3).* ***Conclusiones:*** *La aparición de zonas muertas en la cóclea fue del 33% en la muestra estudiada. Los niños de zonas muertas presentan un peor rendimiento de audiencia en todas las situaciones cotidianas en comparación con los niños sin zonas muertas o pruebas poco concluyentes resultados en la prueba TEN, lo que demuestra un menor beneficio con el uso de audífonos.*

Palabras claves: *Cóclea; Pérdida Auditiva; Niño; Trastornos de aa Audición; Audífonos.*

Introduction

The inner hair cells (IHC) are the sensory cells of the cochlea, responsible for converting the hydromechanical energy into neural impulses. When the IHC lose their functional capacity, i.e. when they are damaged, inactive or absent, they are referred to as the so-called Cochlear Dead Zones. Consequently, the information generated by the vibration of the basilar membrane cannot be transmitted to the central nervous system. In such cases, information overload could occur in the same region, due to energy dissipation and difficulty in decoding the acoustic information. The vibration in other functional areas of the cochlea could compensate for the inactive region, but the vibration of the basilar membrane at a distant location would be less than that which occurs in the dead zone[1].

Hearing aids are the primary means of rehabilitation, and it is essential that children be fitted as early as possible, as soon as the hearing loss diagnosis has been made, thereby avoiding the deleterious effects of sensory deprivation[2].

However, several studies[3,4,5,6] have shown that in the presence of cochlear dead regions, the affected individual may experience little or no benefit at all from sound amplification, since not always is there observed satisfactory improvement in speech recognition, given that sound information is not properly transmitted to the auditory cortex.

The identification of dead regions in the cochlea and the degradation of speech information are factors that can jeopardize the success when fitting hearing aids, especially in the case of hearing-impaired children, in whom the amplification of speech sounds plays an important role in language development[7].

The effects of cochlear dead regions on the fitting of hearing aids in adults have been widely studied in recent years, whereas studies on children have remained scarce[8]. Conversely, the importance of high-frequency amplification in children has recurrently deserved much more attention in the literature[9,10,11].

Hence, to investigate the presence of cochlear dead regions is fundamental to contributing towards the success of hearing rehabilitation aimed at using more suitable strategies and better results in the process of selecting and fitting hearing aids in order for children to derive the highest benefits from the use of amplification.

Given the above, the hypothesis of this study is that children with hearing loss and cochlear dead regions will encounter greater difficulties in fitting to hearing aids due to the poorer benefits derived from sound amplification. The study objectives were: - To investigate the presence of dead regions in the cochlea in children with sensorineural hearing loss; - To comparatively assess the performance achieved with the use of amplification and the presence of dead regions in the cochlea.

Methods

The study was approved by the Research Ethics Committee at *Santa Casa de São Paulo*, document No. 202/08. Those responsible for the children signed a voluntary informed consent form granting their children permission to participate in the study.

The following exclusion criteria were adopted: children aged between 7 and 12 years having from mild to severe sensorineural hearing loss, regardless of audiometric configuration, and fitted to wearing hearing aids for at least six months.

Data collection was performed in two stages performed on the same day, with an average total duration of one and a half hours.

The chosen procedure for assessing the presence of dead regions in the cochlea was the TEN (Threshold Equalizing Noise) test. For conducting the study, the recommendations proposed by Moore et al[12], described below, were followed.

Firstly, absolute thresholds were assessed by air conduction, using 2 dB intervals for greater precision. After obtaining the absolute thresholds, the same procedure was performed in the presence of ipsilateral masking noise, called ERB - Equalizing Rectangular Bandwidth, which can also mask a wide range of frequencies (from 125 to 15000 Hz).

The noise level is calibrated to be equivalent to the sound pressure level of audibility thresholds. For conducting the test, the TEN noise and the sinusoidal signal, both recorded in independent channels on a CD, are presented by means of supra-aural phones. For this, a two-channel Aurical Plus Madsen audiometer connected to a computer was used, so that both masking and test signal could be ipsilaterally presented.

The absolute audibility thresholds of the following frequencies were investigated: 250, 500, 1000, 1500, 2000, 3000 and 4000 Hz in one ear only. Such criteria were chosen in order to make the examination speedier, aiming at the frequencies that are most important for speech discrimination. The ear chosen for testing should meet the inclusion criteria as to the degree of hearing loss.

According to the author, the masked threshold (MT) was considered as indicative of cochlear dead regions, at any given frequency, when at least 10 dB above the absolute threshold (AT) and 10 dB above the masking noise (ERB). If MT was equal to LA or if there was observed a change in the threshold of up to 9 dB, the result was considered negative for the occurrence of dead regions in the cochlea.

It should be noted that in 2004 a test upgrade to TEN (NA) was proposed, in which all intensity levels are specified in dB HL, rather than dB SPL, thus facilitating the comparison of conventional audiometry absolute thresholds to the masked thresholds with test administration. The new guidelines recommend the test be conducted from 500 to 4000 Hz with masking intensity at only one noise level, from 85 to 90 dB/ERB[13].

After this step, the child's parent or guardian answered the PEACH (Parent's Evaluation of Aural/Oral Performance of Children) questionnaire.

The PEACH questionnaire was developed by Ching and Hill[14] and adapted to Brazilian Portuguese by Levy (2007)[15] to be answered by parents or guardians, and aimed to characterize the child's performance making use of sound amplification. The questionnaire consists of 11 questions, including six related to the child's performance in quiet environments, and five involving noisy environments. The questionnaire was administered as an interview, and the parents/guardians had the following response options: never (0%); rarely (25%); sometimes (50%); often (75%); and always (over 75%). The score is calculated based on the responses ("never" = zero; "rarely" = one; "sometimes" = two; "often" = three; and "always" = four points) in each domain: quiet, noise and total.

Parametric statistical tests were used, since the conditions for using them were met. For a comparison analysis among the groups regarding gender and the ear tested, the two-ratio equality test and ANOVA, for the variable age, were used. ANOVA was also used when comparing the groups with regard to the responses to the PEACH questionnaire in all of its domains. A significance level of 0.05 (5%) was established for the analysis of results; all significant values are indicated with an asterisk. All confidence intervals were computed with 95% statistical confidence. The SPSS V16 and Minitab 15 software packages were used for the statistical analysis of data.

Results

We evaluated 15 children, aged between 7 and 12 years. According to the statistical analysis, this sample size allows us to estimate a nominal error of around 7% and a statistical error of 5%. Of these subjects, nine were male and six, female. The distribution of the study group according to age and gender is shown in Table 1.

Table 1. Characterization of the study group according to age and gender.

Age Group	Gender Male		Female		Total	
	N	%	N	%	N	%
7 ├ 9	5	33.3	4	26.6	9	59.9
10 ├ 12	4	26.6	2	13.3	6	39.9
Total	9	60	6	40	15	100

An average age of 8.85 years was observed among the participants in this study, with 60% of the subjects being male and 40%, female.

Since the TEN test requires attention and consistent behavioral responses from the child, it was decided that only one ear would be evaluated. The inclusion criteria needed to be satisfied when choosing the ear to be evaluated.

The amount of time required for carrying out the test in each ear was approximately one hour.

According to the responses obtained in the TEN test, we classified the subjects into 3 groups: G1 (Group without evidence dead regions); G2 (Group with evidence of dead regions); and G3 (Group with inconclusive responses), as shown in Figure 1. The absolute threshold averages of the three groups are shown in Figure 2.

Although there are differences among the percentages of the groups, those were not statistically significant with respect to gender or age.

With respect to the responses received to the PEACH questionnaire, a graph was drawn (Figure 3) with the scores as per the authors' recommendations[14]. In general, it can be observed that parents/guardians rated the children's performance in noisy situations as being worse than that observed in everyday, quiet situations.

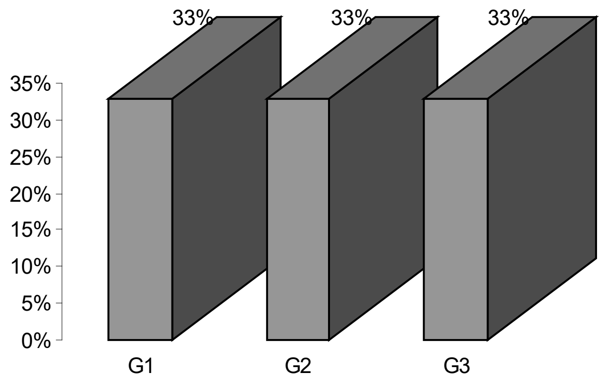

Figure 1. Classification of groups according to the results obtained in the TEN test: G1 (Group without evidence of dead regions); G2 (Group with evidence of dead regions); and G3 (Group with inconclusive responses).

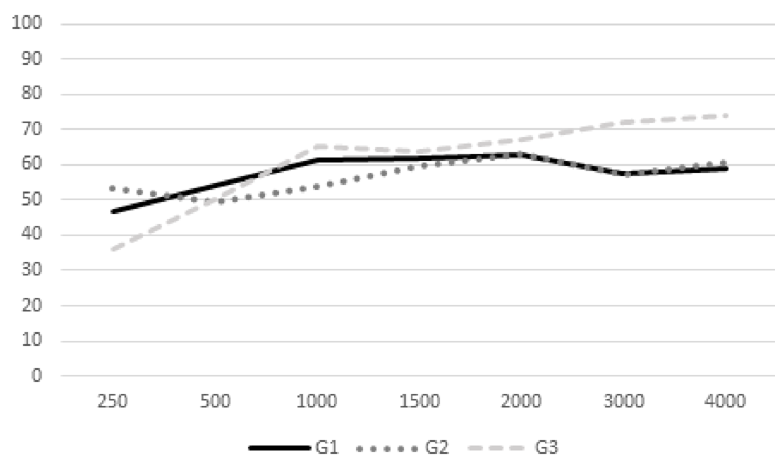

Figure 2. Absolute audiometric threshold averages for G1 (without evidence of dead regions); G2 (with evidence of dead regions); and G3 (with inconclusive responses).

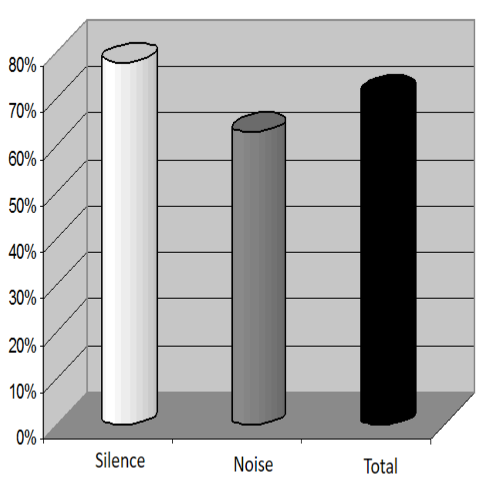

Figure 3. PEACH scale average score results.

For purposes of comparison and analysis, the same division as the one previously used in the TEN test constituted the classification of the three groups. Group 1 consisted of subjects without evidence of dead regions in the cochlea; Group 2 consisted of individuals with evidence of dead regions in the cochlea, at one or more frequencies; and Group 3, in turn, consisted of subjects with inconclusive responses in the TEN test.

Considering the results obtained, children without evidence of dead regions in the cochlea performed better, both in quiet and noisy situations, than did children who had evidence of dead regions or whose responses were not conclusive in the TEN test. Overall, G1 had an 85% performance percentage in everyday sound situations, versus 63% for G2 and 65% for G3 (Figure 4).

In order to determine the precision of the differences between groups, they were compared in pairs (Tukey's Multiple Comparisons test). With this, we were able to conclude that there are statistically significant differences among the groups in all PEACH domains (Table 2).

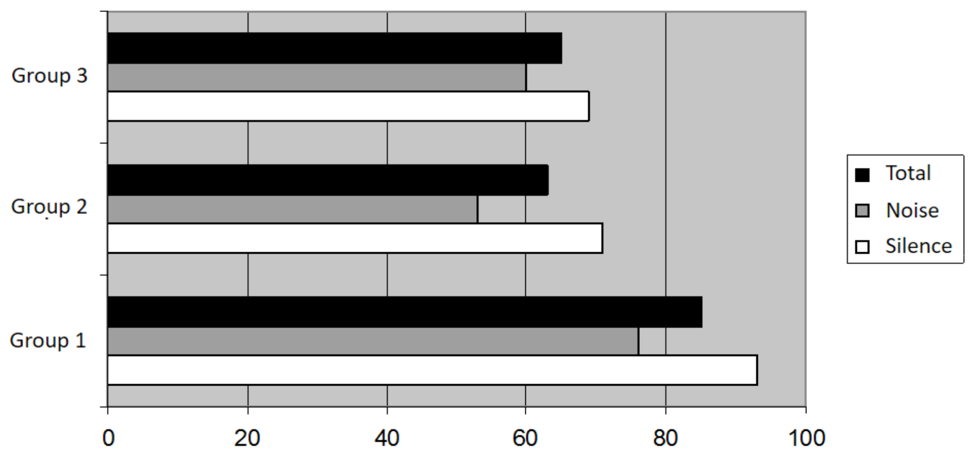

Figure 4. Average scores in the PEACH questionnaire (quiet and noise situations, and overall), according to groups G1 (without evidence of dead regions), G2 (with evidence of dead regions), and G3 (with inconclusive responses).

Table 2. PEACH domain P-values for all groups (G1, G2, and G3)

		G1	G2
PEACH silence	G2	0.080#	
	G3	0.049*	0.959
PEACH noise	G2	0.003*	
	G3	0.032*	0.433
PEACH TOTAL	G2	0.006*	
	G3	0.010*	0.946

Discussion

The TEN test was previously considered as a tool that could be administered to schoolchildren without further adjustments[16]; consequently, TEN was conducted as recommended by Moore et al[12].

The frequencies assessed were: 250, 500, 1000, 1500, 2000, 3000 and 4000 Hz, and the thresholds were surveyed at 2 dB intervals for greater precision[17]. There are many studies in the literature reporting research into and prevalence of dead regions in the cochlea at high frequencies with descending configuration[18,19,20]; nevertheless, in this study, not only have we prioritized the frequencies that are most important for speech intelligibility, but also aimed at reducing the length of time required for administering the test.

Five subjects (33%) showed evidence of dead regions in the cochlea, i.e. upon presentation of the masking noise, the threshold differed by 10 dB or more from the absolute threshold and noise level that were used[12]. According to the literature, a hearing loss exceeding 65 dB at frequencies above 2000 Hz and 55 dB at frequencies below 2000 Hz indicate the existence of impairment not only of the outer but also of the inner hair cells[21]. With the findings of this study, we can affirm that our results are indicative of dead regions in the cochlea both at high and low frequencies.

The frequencies at which dead zones in the cochlea were found were 250, 1500, 2000 and 4000 Hz[22], with a higher occurrence of findings at 2000 Hz. In this study, it was not possible to investigate the occurrence of dead regions in the cochlea at frequencies higher than 4000 Hz due to the criteria used in this investigation regarding the choice of the frequencies that are most important for speech intelligibility.

Another five subjects (33%), who did not show evidence of dead regions in the cochlea, exhibited masked thresholds up to 9 dB higher in relation to absolute values and noise intensity.

Table 3. Absolute audibility and masked thresholds at the frequencies of 250, 500, 1000, 1500, 2000, 3000, and 4000 Hz.

Subjects	Frequencies (Hz) 250		500		1000		1500		2000		3000		4000	
	AT	MT (noise)	AT	MT (noise)	AT	MT (noise)	AT	MT (noise)	AT	MT (noise)	AT	MT (noise)	AT	MT (noise)
1	72	90 (82)	70	89 (80)	75	93 (85)	76	98 (86)	70	89 (80)	59	77 (69)	60	79 (70)
2	35	35 (45)	62	70 (72)	60	65 (70)	62	66 (72)	58	64 (68)	51	56 (66)	55	61 (65)
4	62	78 (72)	52	68 (62)	63	82 (73)	62	81 (72)	61	85 (71)	45	60 (55)	50	68 (60)
6	55	77 (65)	52	70 (62)	58	77 (68)	70	93 (80)	67	92 (77)	58	75 (68)	63	80 (73)
9	56	70 (66)	64	78 (74)	70	88 (80)	70	89 (80)	71	84 (81)	66	85 (76)	63	81 (73)
10	66	85 (76)	60	78 (70)	73	90 (83)	68	87 (78)	74	93 (84)	65	80 (75)	66	85 (76)
12	33	44 (43)	33	38 (43)	17	17 (27)	35	42 (45)	68	90 (78)	68	86 (78)	75	Absent (85)
13	45	62 (55)	40	58 (50)	55	70 (65)	55	71 (65)	50	72 (60)	55	70 (65)	55	70 (65)
14	40	40 (50)	37	43 (47)	49	63 (59)	55	65 (65)	58	70 (68)	52	60 (62)	53	62 (63)
15	37	46 (47)	48	55 (58)	55	70 (65)	53	67 (63)	54	65 (64)	53	60 (63)	58	70 (68)
Average	50	63	52	65	58	72	61	76	63	80	57	71	60	76

Caption:
AT = Absolute Threshold
MT = Masked Threshold
■ = evidence of dead region (difference equal to or greater than 10dB)

We need to point out some aspects of the difficulties encountered while implementing it. The tool has proven to be applicable, but, as expected, it required a long amount of time for assessing hearing thresholds due to the fact that it requires attention and concentration from the participating children. Other factors, such as hearing discomfort upon the presentation of the masking noise and high absolute thresholds preventing the application of noise due to the equipment's maximum output, were also present and constituted a group of inconclusive responses. (Moore et al., 2003). Another five subjects (33%) with these characteristics made up the group with inconclusive responses.

According to the response obtained in the TEN test, three groups were formed: G1 (Group without evidence of dead regions); G2 (Group with evidence of dead regions); and G3 (Group with inconclusive responses).

The results of this study corroborate the existing evidence that it is not possible to identify dead regions in the cochlea based on audiogram findings[23-24]. The pure-tone averages found among the three groups are similar, as shown in Figure 2. This study found evidence of dead regions at different frequencies regardless of the degree of hearing loss and differences in existing thresholds between frequency octaves.

Conversely, there is evidence that when the audiogram has a very steep slope or the threshold worsens considerably with increasing frequency, this should be taken as preliminary evidence for a high-frequency dead region. However, dead regions may also be present even when the audiogram does not show a steep inclination[25]. Another study suggested dead regions in the cochlea can be predicted through the absolute threshold at 4 kHz, when this is greater than 70 dB HL, regardless of the slope of the audiometric curve[26].

Following completion of the TEN test, those responsible for the children (in most cases, the mothers, except for one brother and one grandmother, in two cases) answered the PEACH questionnaire. It must be emphasized that the use of questionnaires allows us to obtain subjective measurements based on the subject's judgment or perception – and, for this reason, it was important that those responsible for the children had a daily and constant interaction with them, since the questions were related to the performance of the child making use of hearing aids in everyday situations.

It was observed that individuals with dead regions had better speech recognition in quiet situations and with low noise level; nevertheless, there was observed no benefit when the noise was more intense[27]. Individuals without dead regions benefited in both situations, which can be seen in G1. Group 2 showed a 63% performance average versus 85% for Group 1; a difference of 22.2%.

As for the performance of the group with inconclusive responses (G3), the subjects performed worse in situations surveyed by the PEACH questionnaire. Users of hearing aids with cochlear dead regions reported that pure tones sounded like noises or distorted, which could cause difficulty in undergoing the TEN test in the presence of noises[12]. Such statements could indicate that, in the group with inconclusive responses, there might be subjects with dead regions in the cochlea.

The findings of this study have therefore demonstrated that the group with evidence of dead regions performed worse, thus showing a lower benefit obtained from the use of amplification in everyday situations[28]. There are currently discussions about hearing performance with amplification at high frequencies, in those cases where there is a suspicion of cochlear dead regions[29-30].

Conclusion

Considering the results obtained, the conclusions drawn were: the occurrence of cochlear dead regions in children with sensorineural loss, assessed by means of the TEN test, was 33%; children with evidence of dead regions in the cochlea performed worse in the PEACH questionnaire in both of the everyday situations surveyed (silence and noise) when compared to children without evidence of dead regions or inconclusive results in the TEN test, possibly exhibiting a smaller benefit from the use of sound amplification.

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