Speech perception: performance parameters and implications for speech therapy with hearing impaired children

Percepção de fala: parâmetros de desempenho e implicações na intervenção fonoaudiológica com crianças com deficiência auditiva

La percepción del habla: los parámetros de rendimiento y las implicaciones para la terapia del habla a los niños con pérdida auditiva

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Abstract

Introduction: *Electronic devices can give access to sound information for children with hearing impairment. In order to assess the child's performance, the development of listening skills and the effects of auditory rehabilitation programs, procedures are needed to assess the perception of speech sounds.* ***Objective:*** *To discuss performance parameters of changes in perceptual skills / speech production of children with hearing loss over six months of the therapeutic process.* ***Method:*** *application of the WASP instrument and the Confusion Matrix in four children with hearing loss.* ***Results:*** *performance parameters proposed by WASP appeared to be more sensitive to attempts of repeating the words, which do not always result in settlement. The use of the proposed criteria was efficient to characterize the hearing ability in word recognition in children with different degrees of hearing loss. The Confusion Matrix permitted*

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further analysis of the phoneme substitutions, and a control of the occurrence of these in each list of words, giving the audiologist a parameter of the variables that may contribute to a better performance. ***Conclusion:*** *the instruments used to analyze errors, WASP and Confusion Matrix, allowed for a detailed description of how the individual uses the acoustic cues available in its auditory dynamic area. Analysis of these results together with audiometric thresholds, amplification and clinical history may lead to a refinement of the expectations of the child's auditory potential and, therefore, have implications in establishing therapeutic goals.*

Keywords: *Hearing loss; Speech Perception; Hearing Aids.*

Resumo

Introdução: *Dispositivos eletrônicos dão acesso à informação acústica para pessoas com deficiência auditiva. Para avaliar o desempenho da criança, o desenvolvimento das habilidades auditivas e os efeitos de programas de reabilitação são necessários procedimentos que avaliem a percepção de fala.* ***Objetivo:*** *discutir diferentes parâmetros de desempenho das habilidades de percepção/produção de fala de crianças com deficiência auditiva usuárias de aparelhos de amplificação sonora (AASI) antes e após intervenção fonoaudiológica.* ***Método:*** *aplicação do instrumento WASP e Matriz de Confusão em quatro crianças com deficiência auditiva, com perdas auditivas severa e profunda, usuárias de AASI, que realizam terapia fonoaudiológica numa abordagem oral.* ***Resultados:*** *Os parâmetros de desempenho do WASP foram mais sensíveis para as tentativas de repetição das palavras, as quais nem sempre resultaram em acerto. Os critérios estabelecidos foram eficientes para caracterizar a capacidade auditiva no reconhecimento de palavras em crianças com diferentes graus de perda auditiva****.*** *Já a Matriz de Confusão permitiu um aprofundamento na análise das substituições de fonemas, e um controle da ocorrência destes nas listas de palavras, oferecendo um parâmetro das variáveis que podem contribuir para um melhor desempenho de produção/percepção de fala.* ***Conclusão:*** *os instrumentos utilizados na análise dos erros permitiram uma descrição detalhada de como o indivíduo utiliza as pistas acústicas disponíveis em seu campo dinâmico de audição. A análise destes resultados conjuntamente com limiares audiométricos, amplificação e a história clínica podem levar a um refinamento das expectativas em relação ao potencial auditivo e implicações no estabelecimento de metas terapêuticas.*

Palavras-chave: *Perda Auditiva; Percepção da fala; Auxiliares de Audição.*

Resumen

Introducción: *Dispositivos electrónicos dan acceso a la información acustica para las personas con discapacidad auditiva. Para evaluar el desempeño de niños el desarrollo de las habilidades auditivas y los efectos de programas de rehabilitación, se necesitan procedimientos para evaluar la percepción del habla.* ***Objetivo:*** *Discutir distintos parámetros de rendimiento de las habilidades de percepción/producción del habla de niños con discapacidad auditiva usuarios de audifonos, antes y después de intervención fonoaudiológica.* ***Método:*** *aplicación del instrumento WASP y Matriz de Confusión a cuatro niños con discapacidad auditiva, con perdidas auditivas severa y profunda, usuários de audifonos, que tuvieron terapia fonoaudiológica con abordage oral.* ***Resultados:*** *los parámetros de rendimiento del WASP fueron más sensibles para los intentos de repetición de palabras, que ni siempre resutaron en acierto. Los criterios propuestos fueron eficiente para caracterizar la capacidad auditiva en el reconocimiento de palabras en niños con distintos grados de pérdida auditiva. La Matriz de Confusión permitió profundizar el análisis de las sustituciones de fonemas, y controlar la ocurrencia de estos en cada lista de palabras, ofreciendo un parámetro de las variables que pueden contribuir a un mejor rendimiento de producción/percepción del habla.* ***Conclusión:*** *los instrumentos utilizados en el análisis de los errores, permitieron una descripción detallada de cómo el individuo utiliza las señales acústicas disponibles en su campo dinámico de audición. El análisis de estos resultados, junto con los umbrales audiométricos, la amplificación y la historia clínica puede conducir a un refinamiento de las expectativas a respeto del potencial auditivo y tienen implicaciones en el establecimiento de objetivos terapéuticos.*

Palabras claves: *Pérdida Auditiva ; Percepción del Habla ; Audífonos.*

Introduction

Hearing loss may be, to a certain extent, compensated by the use of electronic devices, which can provide access to the acoustic information in terms of audibility. However, procedures to assess speech sound perception are necessary to evaluate the child's performance with these resources, the development of auditory skills, and the effects of auditory rehabilitation programs[1,2,3]. Within this perspective, the improvement of therapeutic actions and the practice of systematic evaluations to delimitate how the hearing impaired child perceives and produces speech sounds are needed, since the perception/production relationship may be an indicator of her potential to develop oral language.

Speech perception and production are both complex processes that involve different skills, abilities, and knowledge at several levels. The perceptual experience determines production characteristics, while the possibility and the experience with speech production may, in turn, change its perception. The developmental differences between children with hearing loss are due to the quantity and quality of the opportunities they have to experience perception/production, which leads to auditory feedback alterations and, consequently, determines speech peculiarities[4]. Thus, it is important to evaluate speech perception to measure how much information a hearing impaired child is able to extract from the acoustic signal that gets to her dynamic auditory field, for the better the use of acoustic information, the better the chances to develop oral language.

It is known that the maximum use of hearing is the basic condition to the development of oral language in hearing impaired children fitted with hearing aids. Hence, the identification of speech sounds is a challenge, and when there is a lack of increase in the use of oral language, the acoustic information may not be enough.

The implications of the use of residual hearing in the development of the oral language of children with hearing loss make necessary a more precise register and follow up of speech perception and production with the use of hearing aids, as well as the monitoring of their improvements regarding hearing, orality, and language in the therapeutic process. There is a need for methods of speech perception assessment that evidence the level of development of the patient's auditory skills, help to monitor the effectiveness of hearing aids and cochlear implants, and evaluate the efficacy of habilitation or rehabilitation programs and their techniques during the therapeutic process[5].

The elaboration of speech sound perception assessment procedures is a challenge. Specific procedures, compatible with the child's age and the degree of hearing loss are necessary to obtain the desired information regarding auditory skills[6]. Many tests have been developed with the aim to evaluate the recognition of several types of speech material, including monosyllable and dissyllable words, sentence identification, phoneme discrimination and identification, and suprasegmental aspects of speech. Some of these tests are specific for the assessment of children or adults/elderly, and are designed to verify possible auditory processing or speech perception alterations in individuals with minimal hearing ability. Several Brazilian authors have also conducted studies with the aim to develop instruments to assess speech perception in Brazilian Portuguese, and some auditory perception procedures were specifically implemented to evaluate speech perception in subjects with hearing impairment[4,7].

For Woods, Yund and Herron[8], some phonological factors that are due to different types of stimuli may result in differences in the identification of consonant phonemes, as they found greater identification of consonants in words than in meaningless syllables.

Koch[9] proposed a program of systematic activities to promote the "instant recognition of the phoneme". The aim of the Word Association for Syllable Perception (WASP) protocol is to identify a model of auditory perception error. This protocol was adapted to Brazilian Portuguese by Novaes[10]. Studies have been conducted in the last decade using the WASP protocol to evaluate children with hearing aids and/or cochlear implants. The authors have concluded that the criteria resulting from the WASP proposal were the most sensitive to correct attempts that did not actually result in the correct word. The analysis of different criteria allowed a broader view of the children's speech perception and production abilities, contributing to the clinical practice by guiding the therapeutic objectives according to each child's needs[11,12,13].

With regards to the findings of a few studies[11,12] that reported a higher number of correct phonemes when compared to the number of correct words,

Boothroyd[15] emphasized the importance of using the phonemic score, instead of simply verifying the number of correct words the child produced in speech perception tests.

The aim of this study was to discuss different performance parameters used to evaluate the speech perception/production abilities of four hearing impaired children fitted with hearing aids, before and after speech-language intervention. Moreover, the study had the objective to compare the assessment instruments presented and to analyze its advantages and disadvantages, discussing their potential use in clinical speech, language and hearing practice.

Methods

Subjects

The selection of subjects was conducted in an institution that provides outpatient speech-language therapy for hearing impaired children and their families, based on the following criteria: oral language as the main communication mode; to be enrolled in speech-language therapy for at least one year; and absence of oral sensorimotor alterations with potential to impair speech production.

Four subjects (two boys and two girls) with ages between 5 and 8 years were selected for the study. All of them used hearing aids and presented bilateral sensorineural hearing loss, with degrees varying from moderate to profound.

In order to comply with the ethical precepts of research with human beings, the subjects' caregivers received an informative letter and the free and informed consent, which explained the objective and the procedures of the research (Research Ethics Committee protocol number 0110 – PUCSP). All subjects had the consent signed by their caregivers.

Materials

WASP

According to the model proposed by the authors[9,10] of the assessment protocol of phoneme perception and production, six lists of monosyllable, dissyllable and three-syllable words were produced. The words presented different difficulty degrees, considering the occurrence of phonemes in Portuguese and children's familiarity with the words to facilitate production. Each list comprised 24 words, totaling 144 words, 652 phonemes, 330 vowels, and 322 consonants. Phonetic balance was not taken into account in the elaboration of the lists. It is worth reminding that, according to Harris et al.[19], such procedure do not influence the recognition values of words in patients with sensorineural hearing loss. The words of the lists were chosen based on the familiarity of the subjects with them, since they had restricted vocabularies. The use of familiar lexicon is, in fact, suggested by several authors[20] as an important aspect to be considered in the construction of speech perception assessment procedures, because, otherwise, the children tend to produce words that are closer to those already in their vocabulary[14]. The use of unfamiliar lexicon may lead to erroneous conclusions regarding the subject's ability to recognize speech sounds.

It is also important to emphasize that, in one of the lists, the absence of production of the archiphoneme in infinitive verbs was not considered as error, since it is commonly omitted in everyday oral language and phonetic balance was not performed.

During the assessment procedure, the researcher presented the words in a speaker, using a shield to avoid lip reading. This procedure prevented the stimuli presentation during speech-language therapy and during the children's attention period in which the task was performed in an open set, that is, the child repeated the words with no alternatives of response.

The following parameters were used on the lists to characterize the consonants according to their linguistic traits: manner of articulation (M), place of articulation (P), and voicing (V).

The assessment criterion of the test is based on the children's responses. The speech stimuli (words) are presented in the first column. The second column displays the child's production. Each word/stimulus may be individually marked according to the phoneme's perception and production. The mark is obtained by the total individual marks in the column. The total marks obtained in the columns is indicated in the error model for the production of the manner, voicing, and place (initial, medial or final) of each consonant, with the production of vowels and diphthongs. In the answer sheet, each blank space was filled with a symbol, according to the subject's response. When the child answered to the sound stimulus with the right phoneme, the space was filled with a (Ú); if the phoneme presented was omitted, a (f) was marked;

and if a different phoneme was produced, a (-) was marked to indicate an auditory discrimination failure (manner, voicing, or place of articulation)[11].

Confusion Matrix

After the WASP protocol was applied, it was conducted a word discrimination and recognition analysis using the Confusion Matrix[16,17], which contains only Brazilian Portuguese consonants. The data fed into the Confusion Matrix result in the comparison of 21 consonants, which is visualized in the crossing of these phonemes. This crossing represents the results of phonemes presented as stimuli (S) *versus* phonemes produced as responses (R), written down in each cell of the Confusion Matrix.

Patients' productions were transposed to the Confusion Matrix considering only the consonant sounds. The percentages of correct consonants, errors (occurrence of phonemic substitutions), and consonant omissions are calculated to characterize the subject's performance.

Procedures

Patients' charts were examined to obtain their histories: etiology, previous audiological data, cognitive development, and specific characteristics. The children selected for the study were submitted to audiological evaluation and had their hearing aids checked before the WASP lists were applied.

The assessments were conducted with each child separately, in a silent room, using a shield to avoid lip reading.

After the lists were applied and the subjects' responses were registered, the word productions were transcribed into the WASP table to quantify the different types of errors. Then the data were transferred into the Confusion Matrix. After six months of speech-language intervention, the same procedures were conducted once again.

Data analysis

Children's performance on the WASP protocol and the Confusion Matrix allowed the error analysis at different perspectives. The variables analyzed based on the WASP were: number of correct monosyllable words; number of correct disyllable words; number of correct monosyllable – disyllable words; number of correct three-syllable words; total number of correct words; number of correct vowels; number of correct consonants; number of correct phonemes; Confusion Matrix (omissions); Confusion Matrix (phonemic substitutions); number of correct consonants (manner of articulation); number of correct consonants (voicing); number of correct consonants (place of articulation); total error pattern; and consonant error pattern. The Confusion Matrix allowed the analysis of phonemic omissions and errors. Each application of the lists, before and after speech-language intervention, was separately analyzed, and the averages were compared using the Paired t-Student test[18].

Results

Although there was not enough evidence to reject the hypothesis of equality of means of the variables "mean number of monosyllable words" and "Confusion Matrix – phonemic substitutions" in both assessments, the p-values are close to the significance level adopted ($p<0.05$), hence the conclusions regarding these variables could be different if the sample was greater than four (Table 1 and Figure 1).

A separate quantitative analysis of the responses of the children in this study was carried out. The averages obtained in both applications of the WASP protocol were compared using the Paired t-Student test[18].

The mean number of correct monosyllable words was not considered different between assessment and reassessment ($p=0.135$). However, significant differences were observed between applications for the mean numbers of correct disyllable words ($p=0.076$), monosyllable – disyllable ($p=0.068$), three-syllables ($p=0.029$), and total of correct words (0.004). The means were higher in the second application, that is, after speech-language intervention.

In the phonemic count of the lists, a difference was found between the numbers of correct phonemes in the first and the second application. Based on the analysis of the mean correct responses, the p-value for the comparison between phonemes was significantly different ($p=0.014$). Both vowels ($p=0.069$) and consonants ($p=0.018$) presented higher averages in the second application of the WASP. This allowed a quantitative analysis of the correct responses. Considering the variance

Table 1. Total number of items, mean number of correct items in each application, mean difference of correct items, value of the t statistics and corresponding descriptive level of the test (p) in each hearing situation.

Hearing assessment parameters	Category	Total number of items	Mean number of correct items		Mean difference	t	p
			1st application	2nd application			
Words	Monosyllable	24	16.50	19.00	-2.50	-1.35	0.135
	Disyllable	48	26.00	34.25	-8.25	-1.91	0.076*
	Monosyllable and disyllable	24	10.50	13.75	-3.25	-2.03	0.068*
	Three-syllable	48	24.50	40.25	-15.75	-2.99	0.029*
	TOTAL	144	77.5	107.2	-29.75	-6.33	0.004***
Phonemes	Vowels	330	296.50	320.70	-24.20	-2.01	0.069*
	Consonants	322	228.80	274.70	-46.00	-3.61	0.018**
	TOTAL	652	531.20	592.70	-61.50	-3.97	0.014**
Consonants	Manner	322	235.30	279.30	-44.00	-3.58	0.019**
	Voicing	322	243.50	287.50	-44.00	-2.53	0.043**
	Place	322	224.80	274.50	-49.80	-3.05	0.028**
Confusion Matrix	Omissions	322	66.00	31.00	35.00	2.39	0.049**
	Substitutions	322	25.25	18.75	6.50	1.49	0.117
Total error pattern		1296	1005,20	1156.30	-151.00	-3.11	0.026**
Consonant error pattern		966	702,00	839.70	-137.88	-3.08	0.028**

* p < .10
** p < .05
* **p < .01

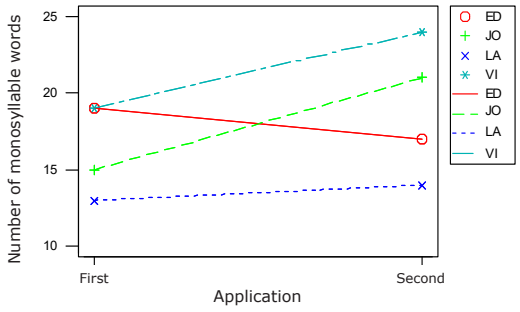
analysis, it was also concluded that, for the consonants, in average, the number of linguistic traits perceived by the children increased in the second application for manner of articulation (p=0.019), as well as for voicing (p=0.043) and place of articulation (p=0.028).

The Tukey test was used to compare the means in order to identify the differences. It showed an increase in the number of correct responses in the second application of the lists of words. There was also an improvement in the number of correct phonemes, in the total error pattern, and in the consonant error pattern.

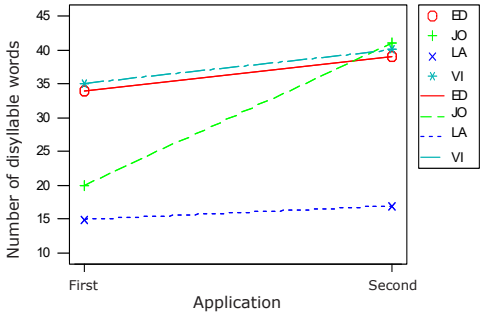
The analyses of variance showed the following values: p=0.004 for the total of words; p=0.028 for the consonant error pattern (place of articulation); and p=0.026 for the total error pattern. These data seem to indicate that the consonant error pattern and the total error pattern are indicators of improvements in the auditory perception and, consequently, in the recognition of words. Because they are more easily identified, the vowels did not contribute to the speech perception assessment, as they were already perceived in the first application.

The percentage of correct phonemes in the Confusion Matrix that corresponded to the second application of the WASP increased in all cases, providing better acoustic information for the children to understand speech. The mean number of omissions was smaller in the second application (p=0.049); however, the mean number of substitutions (phoneme errors) was not different from the first to the second application (p=0.117). The results obtained led to a more detailed analysis, since the characteristics of substitutions, omissions and correct responses evidence the acoustic characteristics of the phonemes included in the Confusion Matrix.

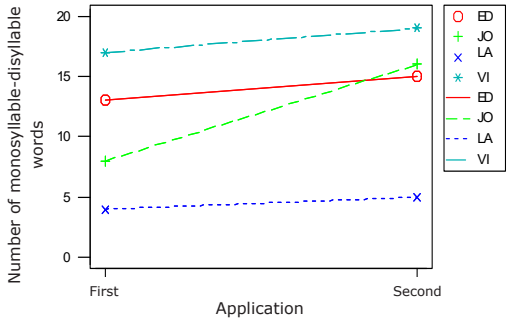
The recognition of words for each individual in both applications of the WASP lists is represented in Figure 2.



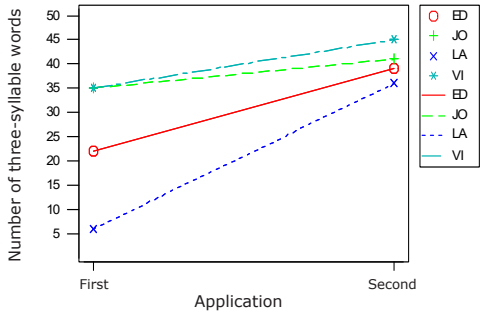
(a) Monosyllable (N=24)



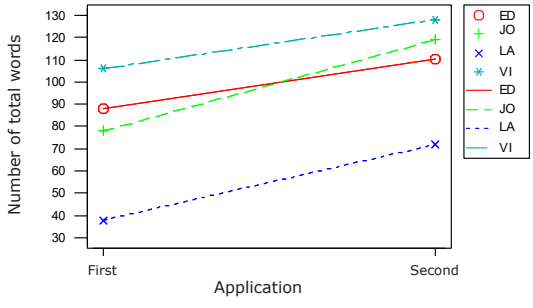
(b) Disyllable (N=48)



(c) Monosyllable- disyllable (N=24)



(d) Three-syllable (N=48)



(e) Total words (N=144)

Figure 1. Number of correct items observed by individual in each application of the lists of words, in the categories monosyllables, disyllables, monosyllables – disyllables, three-syllables, and total words.

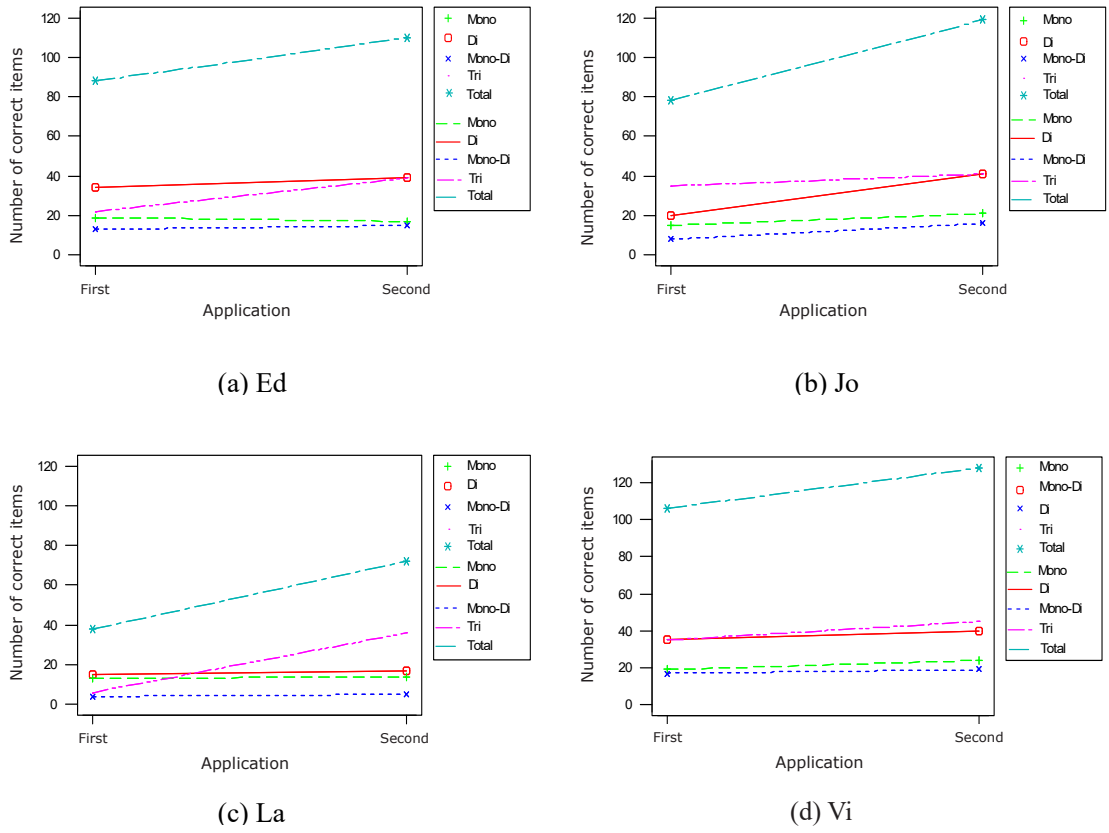


Figure 2. Number of correct items observed in the categories monosyllables, disyllables, monosyllables – disyllables, three-syllables, and total of correct words in each application of the lists, by individual, using relative values.

Discussion

The different performance parameters proposed by the WASP protocol[9] seem to be more sensitive to the attempts of word repetition, which not always resulted in correct responses. The results obtained in this study suggest that the use of the proposed criteria was effective to characterize the auditory ability of word recognition in children with different degrees of hearing loss. The Confusion Matrix[16] allowed a deeper analysis of the phoneme substitutions observed, as well as a better control of their occurrence in each list of words, providing the speech-language pathologists with a parameter of the variables that may contribute to a better performance.

In the first application of the lists, the percentage of correct word recognition was, for three subjects (Ed, La and Vi), higher for the lists of monosyllable and disyllable words than for the three-syllable lists. This result shows that these children probably needed the visual cue to recognize the meaning of words, that is, they were not using their full auditory potential, since the three-syllable words, due to their length and the quantity of acoustic information they display, would be more easily identified. In fact, according to Boothroyd[15], there is evidence that the linguistic and situational contexts influence speech perception.

In the second application of the lists, which was conducted after six months of speech-language intervention, the children in this study presented a significant increase in the percentage of correct responses, especially in the lists of three-syllable words. This may have occurred because the speech-language intervention focused on the use of hearing abilities to attribute meaning, and thus the three-syllable words were produced correctly more easily. Indeed, semantic cues and the lin-

guistic context seemed to influence speech sound perception[12].

As in previous studies[8,11,13], the recognition of phonemes was better than the recognition of words for all subjects.

The percentage of correct phonemes and the consonant error pattern were better indicators of the phonemic substitutions presented by the children in this study, and were the best representatives of their phoneme perception abilities. Phoneme count provides the speech-language pathologist with a qualitative analysis and a more precise view of the difficulties hearing impaired children face. This study also found similar percentages of total error pattern and correct phonemes.

The consonant error pattern is reflected in the percentage of linguistic traits perceived. The classification of consonant sounds was established, in this study, by the traits manner and place of articulation, and voicing. The acoustic energy related to these traits makes some consonants more audible than others. In general, the voicing of phonemes was the trait most identified by the subjects. This is due to the fact that it generates low-pitched energy, which guarantees that this trait is easily perceived[17].

With respect to the vowels, most of them were identified by the subjects. Omissions occurred when the whole word was omitted, or when the vowel was at the end of the word. The emphasis on the use of residual hearing increased the possibilities of children with hearing impairment – focused here – to receive acoustic information regarding language sounds. The better they can use the acoustic information, the better the chances of these children developing oral language[21], as they used hearing aids.

This was evident in the Confusion Matrix, which allowed a deeper analysis of the phoneme substitutions presented by the subjects, representing more reliably the speech perception ability and, hence, being useful for the selection of hearing amplification mechanisms. The Confusion Matrix derived from the responses on the first application of the lists of words showed that the percentage of omissions was higher than the percentage of phonemic substitutions.

In the first application of the WASP, the Confusion Matrix showed a similar error pattern regarding both phonemic omissions and substitutions in the dispersion of results. These substitutions were randomly distributed, without great concentrations of errors, but many were oriented by the semantic aspect, as subjects looked for words with meanings. In the second application of the lists, the Confusion Matrix showed decrease in the percentage of omissions in all the cases.

Given the need for evaluation methods of speech perception/production abilities, the combination of the assessment instruments WASP[9] and Confusion Matrix allowed to direct the auditory potential of the children and to change the therapeutic strategies.

Conclusion

The WASP protocol seemed sensitive to the attempts of correct responses produced by the children, when the attempts did not result in correct productions, thus producing a better characterization of the auditory potential of each child.

The production of correct words was, in general, worse than the production of correct phonemes in the first application of the word lists. The number of correct phonemes and the consonant error pattern were the best indicators of the auditory abilities involving speech sounds, and thus were the most useful parameters to adjustments in amplification and in the therapeutic strategies.

The Confusion Matrix allowed the analysis of the characteristics of correct responses, phoneme omissions and substitutions, contributing to the therapeutic process as it promotes adjustments in the hearing aids, in the intervention on articulation, and in the use of visual cues.

The use of lists of words that were not phonetically balanced, emphasizing the use of daily words as stimuli, had the advantage of greater facility in their recognition. However, the responses might have suffered interference of the semantic context. The vocabulary used on the lists (monosyllable, disyllable, and three-syllable familiar words) provided a great diversity of phonetic and semantic cues.

The performance differences in the recognition of words and phonemes between children with similar auditory potential (Ed, Vi) seemed to indicate that the greater or lesser use of this potential is directly related to the therapeutic approach with well based objectives and expectations aiming to use the full auditory perception potential of each child.

This study allowed relating assessment instruments and alternative perspectives for the discussion regarding speech sound perception and production in hearing impaired children, contributing to a better delineation of their auditory potential.

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