Original Article

Temporal processing, localization and auditory closure in individuals with unilateral hearing loss

Processamento temporal, localização e fechamento auditivo em portadores de perda auditiva unilateral

Regiane Nishihata[1], Márcia Ribeiro Vieira[1], Liliane Desgualdo Pereira[2], Brasília Maria Chiari[2]

ABSTRACT

Purpose: To assess the behaviors of temporal resolution and temporal ordering, sound localization, and auditory closure, and to investigate possible associations with complaints of learning, communication and language difficulties in individuals with unilateral hearing loss. **Methods:** Participants were 26 individuals with ages between 8 and 15 years, divided into two groups: Unilateral hearing loss group; and Normal hearing group. Each group was composed of 13 individuals, matched by gender, age and educational level. All subjects were submitted to anamnesis, peripheral hearing evaluation, and auditory processing evaluation through behavioral tests of sound localization, sequential memory, Random Detection Gap test, and speech-in-noise test. Nonparametric statistical tests were used to compare the groups, considering the presence or absence of hearing loss and the ear with hearing loss. **Results:** Unilateral hearing loss started during preschool, and had unknown or identified etiologies, such as meningitis, traumas or mumps. Most individuals reported delays in speech, language and learning developments, especially those with hearing loss in the right ear. The group with hearing loss had worse responses in the abilities of temporal ordering and resolution, sound localization and auditory closure. Individuals with hearing loss in the left ear showed worse results than those with hearing loss in the right ear in all abilities, except in sound localization. **Conclusion:** The presence of unilateral hearing loss causes sound localization, auditory closure, temporal ordering and temporal resolution difficulties. Individuals with unilateral hearing loss in the right ear have more complaints than those with unilateral hearing loss in the left ear. Individuals with hearing loss in the left ear have more difficulties in auditory closure, temporal resolution, and temporal ordering.

Keywords: Hearing; Hearing loss; Auditory perception; Hearing tests; Language

INTRODUCTION

The studies related to unilateral hearing loss (HL) started in the 60s and changed the concept that children who have this alteration do not present hearing, communicative, educational or language problems. Usually, unilateral HL is detected later in the life of children, often in the preschool phase[1].

Hearing problems may predict the development of language and other abilities that are essential for a healthy learning development. In normal individuals, the hearing is the only sense in which each ear is represented in both brain hemispheres, as the auditory pathways have both ipsi and contralateral trajectories. Thus, individuals with unilateral loss may have difficulties acquiring speech and language abilities[2].

Unilateral HL can cause auditory processing deficits and, consequently, deficits in the development of language and communication, especially if it occurs in children[3]. Among these deficits we mention the inability to locate the sound, to perform auditory closure, and difficulty in temporal resolution.

The localization of the sound source is regarded as a binaural phenomenon resulting from the interaural time differences and the intensity of the sound stimulus, in which the brain performs an analysis of stimuli that reach both ears to precisely determine the distance, the position and the elevation of the sound source. The phenomenon of binaural summation provides that the sound presented to both ears is perceived as more intense than if it were presented in monaural mode. With the same sensitivity in both ears, the binaural hearing threshold is 3 dB better than monaural, providing less effort to listen. The elimination of the shadow effect refers to the reduction of the signal strength, which

Study conducted at the Graduate Program in Human Communication Disorders, Universidade Federal de São Paulo – UNIFESP – São Paulo (SP), Brazil.
Conflict of interests: None
(1) Graduate Program (Masters degree) in Human Communication Disorders, Universidade Federal de São Paulo – UNIFESP – São Paulo (SP), Brazil.
(2) Graduate Program in Human Communication Disorders, Universidade Federal de São Paulo – UNIFESP – São Paulo (SP), Brazil.
Correspondence address: Regiane Nishihata. R. Príncipe Humberto, 457, Vila Campestre, São Bernardo do Campo (SP), Brasil, CEP: 09725-200. E-mail: regiane.nishihata@yahoo.com.br
Received: 10/25/2010; **Approved:** 12/12/2011

occurs when the signal moves from side to side of the head, especially at high frequencies[1]. The immediate effect of this phenomenon is to improve speech recognition in the presence of noise, a situation that is particularly difficult for those with unilateral HL.

Individuals with difficulty in the ability of auditory closure show failure in the intrinsic redundancy of the central nervous system, reducing or eliminating the repeated representation of the signal that reaches the auditory pathways. Therefore, any complications that would reduce the extrinsic redundancy of the auditory signal may interfere with the ability of the individual to achieve auditory closure. A deficit in this hearing ability can interfere with the ability to decode the phonemic aspects of a speech signal[4] and consequently lead to a difficulty in understanding speech, which can hinder learning, especially in children.

The auditory temporal processing can be divided into four types of listening hearing abilities: temporal ordering or sequencing, integration or temporal summation, temporal masking, and temporal resolution or discrimination[4]. The ability of temporal ordering refers to the processing of multiple auditory stimuli according to their order of occurrence; hence, an individual is able to discriminate the correct order of occurrence of sounds. Temporal resolution is the ability to detect time intervals between sound stimuli or to detect the shortest time in which an individual can discriminate between two audible signals. This ability is extremely important for the understanding human speech, constituting a prerequisite for language abilities, as well as for reading[5]. Recent studies have suggested that research about the functioning of auditory processing in unilateral hearing loss may contribute to the knowledge of the structure and function of the auditory nervous system, especially regarding the temporal aspects of hearing. This is due to the fact that, in general, the auditory cortex in the left brain hemisphere is specialized in the processing of acoustic stimuli with complex temporal structure (including speech), and the right hemisphere is important in the spectral processing and favors tonal stimuli and music. This asymmetry in the processing of sounds is further emphasized when privileged stimuli are presented to the contralateral ear[6,7]. Thus, the assessment of temporal processing in individuals with unilateral HL and comparing the performance according to the ear affected could provide more information about the role of each hemisphere in temporal processing.

Research conducted with individuals with unilateral HL have demonstrated that they are subject to numerous difficulties that can affect normal language development, auditory perceptual abilities, and academic achievement[1,2]. Moreover, many of them report negative feelings about the situations of hearing difficulties[2]. Hence, it is very important to know the auditory, linguistic and academic performances of these individuals, in order to provide better assistance for this population.

The present study had the aim to evaluate the behaviors of temporal resolution and temporal ordering, sound localization, and auditory closure, and to investigate complaints of learning, language and communication difficulties in individuals with unilateral hearing loss.

METHODS

This study was approved by the Research Ethics Committee of the Universidade Federal de São Paulo, under process number 1019/06. A total of 26 individuals aged between 8 and 15 years were selected: 13 had unilateral HL and formed the HL Group (HLG), which was subdivided into: group with HL in the right ear (HLGR) and group with HL in the left ear (HLGL); and 13 had normal hearing, constituting the control group – group without HL (GWHL). The groups were formed by seven female and six male subjects, who were matched by gender, age and level of education.

Inclusion criteria for the HLG were: to present profound unilateral HL; pure tone thresholds in the hearing ear less than or equal to 15 dBHL in the frequencies from 250 Hz to 8 kHz; speech audiometry compatible with pure tone audiometry; normal tympanometry[8]; no evidence of neurological, motor and visual deficits. For the GWHL, inclusion criteria were: to present pure tone thresholds less than or equal to 15 dB HL in the frequencies between 250 Hz and 8 kHz; tympanometric curve type A; to present normal results in the dichotic digits test; no evidence of neurological, motor or visual deficits.

Participants with unilateral HL were selected from the outpatient clinics of the Disciplines of Hearing Disorders and Pediatric Otorhinolaryngology of the Universidade Federal de São Paulo. Individuals from the GWHL had no connection with the institution and were randomly selected. All of them were invited to participate in this research, and their parents signed the free and informed consent form, according to Resolution 196/96.

The procedures used for the selection of subjects were: anamnesis, otoscopy, pure tone audiometry, speech audiometry, tympanometry, and research of contralateral acoustic reflexes. After selection, all participants were submitted to an assessment, as it follows.

Anamnesis

Initially, a questionnaire was administered to parents regarding risk factors for hearing, speech and language development, communication, and academic performance. This questionnaire was based on an interview used in a previous study[2] of American children with unilateral HL. However, some questions were added to better attend the reality of the Brazilian population (Appendix 1). The anamnesis was conducted individually by the researcher in the form of oral interview in appropriate room.

Auditory processing assessment

Auditory processing was assessed through the following tests: Speech-in-Noise, Sound localization in five directions, Verbal and non-verbal sequential memory test, and Random gap detection test (RGDT). The results of each test were registered in a proper recording sheet.

The Speech-in-Noise test consists of the presentation of sequence of 25 words from a recorded CD. Speech stimuli were presented at 40 dB above the mean audiometric

thresholds from 500 Hz to 2 kHz, while white noise was presented in the same ear. The intensity level of each stimulus (speech and noise) was presented in a +5 ratio. The ability assessed is called closure. It should be noted that the stimulus was presented monaurally for both groups; the ears tested were those with normal hearing for the HLG, and the corresponding ears for the GWHL. White noise was introduced ipsilaterally to the stimulus. This test assesses the ability of auditory closure. The normality criterion was set at 70% or more correct answers[9].

The Sound Localization Test is the presentation of high-frequency sounds in five directions (front, above, behind, left and right) in a dichotic task, in which the individual should point the direction of the sound, without visual cues. This test analyzes the hearing ability of sound localization and the physiological mechanism of discrimination of sound source direction. The normality criterion was set at four or five correct answers[9].

In the Sequential Memory Test, verbal (verbal sequential memory) and non-linguistic sounds (non-verbal sequential memory) are presented in a diotic task without visual cues. The Verbal Sequential Memory test used the syllables *pa, ta, ca, fa* in different orders and the individual should repeat the correct sequence. For the Non-Verbal Sequential Memory, the musical instruments agogô with big bell, jingle bells, bell, and coconut were played in different orders, and the individual should point or say the names of the objects in the correct order. This procedure evaluates the hearing ability of temporal ordering. The normality criterion for these tasks was set at two or three correct answers[9].

The RGDT consists of a recorded presentation of a sequence of nine pairs of sound stimuli with short intervals between them, in which the individual is instructed to respond to the examiner whether he/she is listening to one or two sounds (by lifting a finger if he/she heard one sound, or two fingers if he/she heard two sounds). In the RGDT, the recording is played by a CD, which uses a calibration tone of 1 kHz to perform the calibration of the procedure. For the instruction by demonstration, there is a subtest for training, and the evaluation uses four subtests in the frequencies of 500 Hz, 1, 2 and 4 kHz, with intervals of 7 milliseconds (ms) between stimuli. Pure tone stimuli are presented in random intervals of 0 to 40 ms, according to the following specification: 0, 2, 5, 10, 15, 20, 25, 30 and 40 ms. The RGDT was presented at 50 dBHL having as reference the mean hearing threshold for 500 Hz, 1 and 2 kHz. This test analyzes the hearing ability of temporal resolution and the physiological mechanism of temporal processing. The normality criterion was set to lower or equal 10 ms[10].

All subjects were instructed in an open field, before placing the headphone in the booth, and it was certificated if the tests were understood. To compare the results, we determined the average threshold of temporal acuity of the ear in which the test was conducted, that is, the ear with normal hearing thresholds for the HLG and the correspondent ear for the GWHL.

The results of the anamnesis and auditory processing tests were statistically analyzed using the Mann-Whitney and the Equality of Two Proportions tests. The significance level adopted was 5%.

RESULTS

Anamnesis

The mean age among the HLG and GWHL groups was 11.77 years (8 to 15 years). There was no predominance of gender, as 53.84% were female and 46.16% male. Likewise, there was no difference between the ear affected by the HL, because 46.15% had HL in the right ear and 53.85% in the left ear. The mean age of suspicion of hearing loss (HLG) was 3 years and 8 months, and the identification of the loss occurred in average at 4 years and 5 months.

Regarding the etiology of HL was observed that in 53.8% of the cases it was unknown. In 15.4% the etiology of unilateral HL was bacterial meningitis, in 15.4% traumatisms, and in 15.4% mumps.

Anamnesis responses showed that 46.2% of HLG subjects presented delay or alteration in speech and language development, and 66.7% of them had HL in the right ear. They all complained of difficulty in communicating and 76.9% reported academic difficulties; the HLGR presented more complaints (83.3%) than the HLGL (71.4%). From the 13 children with unilateral HL evaluated, 69.2% needed visual cues.

Regarding the academic performance of the HLG, it was observed that 23.1% had repeated at least one school year. Furthermore, 38.5% of them attended school support programs. Likewise, 69.2% of the responsible for the children with HL reported the need for preferential seating in the classroom.

Speech-in-noise test and RGDT

The responses obtained in the speech-in-noise test and the RGDT were analyzed (Table 1). In addition, the groups were compared for both tests (Table 2). In the speech-in-noise test, differences were observed in the comparisons between HLG X GWHL and HLGL X HLGR (Table 2). Moreover, there were also differences between HLGL X GWHL. No difference was found in the comparison between GWHL and HLGR.

The responses for the RGDT were analyzed for all frequencies tested (Figure 1). The HLG presented gap detection thresholds higher than GWHL in all frequencies tested, except for 2 kHz, in which the HLG had a mean threshold very close to that of the GWHL. As for the analysis of the mean responses obtained in the RGDT (Table 1), data show that the HLGL presented gap detection thresholds higher than the HLGR. Nevertheless, there were no differences in any of the comparisons between groups (Table 2).

Sound localization test, verbal and non-verbal sequential memory test

In tests of sound localization, verbal and non-verbal sequential memory, the HLG had fewer correct answers than the GWHL in all tests (Figure 2). There were differences between HLG and GWHL and between HLGR and GWHL in the sound localization test (Table 2). There were no differences in other comparisons for this test.

Table 1. Descriptive statistics obtained for the average of correct answers on the test of speech in noise and the average threshold for the RGDT test by group (with and without hearing loss) and ear (right and left)

Test		Mean (%)	Median (%)	SD (%)	Q1 (%)	Q3 (%)	n	CI (%)
Speech-in-noise	HLG	90.5	96	7.8	88	96	13	4.2
	HLGR	94.7	96	3.3	96	96	6	2.6
	HLGL	86.9	88	8.9	82	94	7	6.6
	GWHL	96.2	96	3.5	92	100	26	1.3
RGDT	HLG	11.25	9	7.02	8	15	13	3.82
	HLGR	7.54	8	3.18	6	10	6	2.55
	HLGL	14.43	15	8.04	9	19	7	5.95
	GWHL	9.48	10	3.84	7	13	13	2.09

Note: RGDT = random detection gap; SD = standard deviation; Q1 = first quartile; Q3 = third quartile; CI = confidence interval for the average; GWHL = group without hearing loss; HLG = group with hearing loss; HLGR = group with hearing loss in the right ear; HLGL = group with hearing loss in the left ear

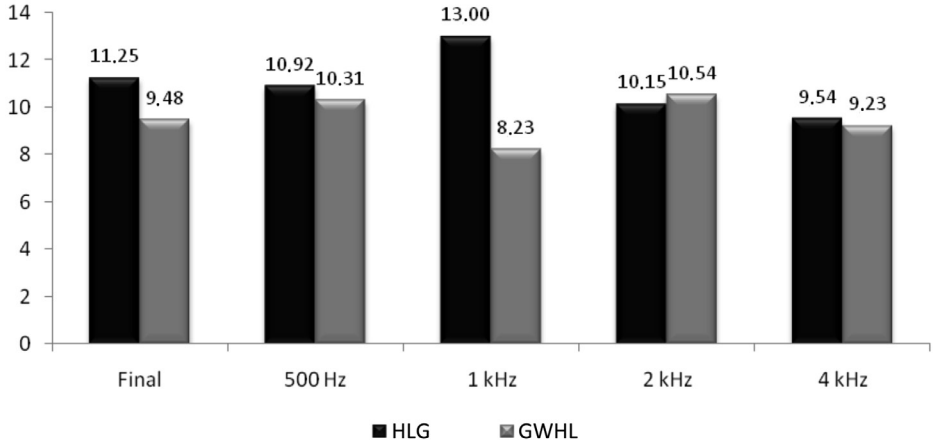
Table 2. Values of p of quantitative variables of speech in noise tests, RDGT, sound localization, MSV and MSNV

Test	HLGR x HLGL	HLGR x GWHL	HLGL x GWHL	HLG x GWHL
Speech-in-noise	0.052#	0.429	0.005*	0.017*
RGDT	0.153	0.287	0.265	0.918
Sound localization	0.596	0.030*	0.104	0.024*
NVSM (4 sounds)	0.877	0.960	0.857	0.931
VSM (4 sounds)	0.210	0.166	0.012*	0.025*

* Significant values (p<0,05) – Mann Whitney's test

Tendency towards significance

Note: RGDT = random detection gap; NVSM = non-verbal sequential memory; VSM = verbal sequential memory; GWHL = group without hearing loss; HLG = group with hearing loss; HLGR = group with hearing loss in the right ear; HLGL = group with hearing loss in the left ear



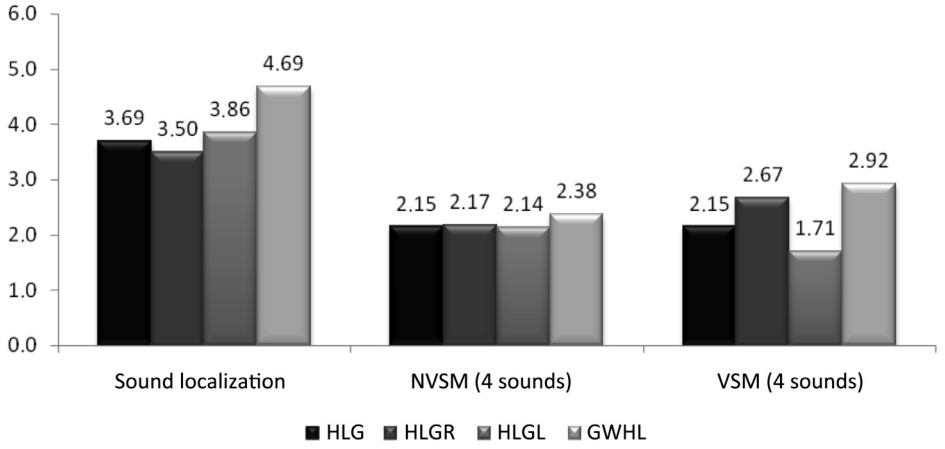
Note: GWHL = group without hearing loss; HLG = group with hearing loss

Figure 1. Temporal acuity thresholds obtained in the RGDT for the groups with and without hearing loss

In the verbal sequential memory test, the mean correct answers for the HLGR was higher than for the HLGL (Figure 2). Statistical analysis showed differences between HLG and GWHL, and between GWHL and HLGL (Table 2). In the other comparisons differences were not significant, as occurred for all comparisons in the non-verbal sequential memory test.

DISCUSSION

The sample consisted of children and teenagers with unilateral HL. It should be noted that the comparison group was matched to the study group considering age, gender and education level, which shows the care taken to ensure that



Note: NVSM = non-verbal sequential memory; VSM = verbal sequential memory; GWHL = group without hearing loss; HLG = group with hearing loss; HLGR = group with hearing loss in the right ear; HLGL = group with hearing loss in the left ear

Figure 2. Mean responses of the groups in the tests of sound localization, non-verbal sequential memory, and verbal sequential memory

demographic aspects would not interfere in the final results.

In the group with unilateral HL it was found that the loss was noticed by close relatives, especially by the mother. The time elapsed between suspicion and diagnosis was of about a year and a half, both occurring in preschool age, a period prior to what occurred in other studies[11,12]. In these, the mean age of diagnosis of unilateral HL occurred between 5 years and 6 months and 8 years and 6 months. Early detection of hearing impairment is an important prognostic factor in favor of the development of speech, language, academic and social aspects of children, which can be quickly inserted into rehabilitation programs that include therapy and/or fitting[13].

We found that the etiology of HL was unknown for a little over half of the cases. These findings corroborate a study that found that in approximately 50% of cases, the etiology of unilateral HL is unknown[14]. Other studies, however, have reported that the etiology is unknown in about 36% of the cases[15,16]. In the present study, other etiologies were acquired throughout life: mumps, meningitis, and traumas. These etiologies are also similar to those found in literature[14,16].

Almost half of the individuals in the HLG complained of delays or alterations in the development of speech and language; most of the responsible mentioned difficulties in the classroom and all reported communication difficulties by the children. There were more reports of difficulties in patients with HL in the right ear. These complaints have been reported in previous studies that showed that most children with unilateral HL, especially those with severe to profound HL, present alterations in the development of speech and language and, consequently, academic difficulties[1,2,16-18]. However, it is very remarkable the great difficulty found in individuals with unilateral HL in the right ear. This probably shows that the neurological immaturity of the auditory pathways of the central nervous system that result from the stimulation of the right ear, that is, of the left hemisphere, contributed to this result. Studies regarding risks for academic performance have verified the existence of a relationship between the ear affected by the HL and limitations in academic performance, since it has been observed that children with HL in the right ear had more school failure than those with HL in the left ear[14,18,19].

The most common complaints related to oral language and academic performance observed in patients with unilateral HL in the right ear may be related to the asymmetry of acoustic information between right and left hemispheres, which is even more emphasized when privileged stimuli are presented to the contralateral ear[6,7,20]. The ability to encode and analyze temporal aspects of acoustic information might be related to the contribution of the left hemisphere for language functions[21]. Thus, HL in the right ear may prevent that acoustic information is normally analyzed by the left hemisphere, hindering the language function to a greater extent in these individuals.

The HLG showed worse responses than the GWHL in the speech-in-noise test. These findings corroborate previous studies that found that children with unilateral HL have speech recognition performance significantly worse even in direct monaural conditions (in the better ear) when compared to normal hearing children[16,20,22-25]. Furthermore, it was observed that the side of the hearing loss influenced responses of the HLG, and the HLGL showed worse results. These findings disagree with a similar study that found that individuals with HL in the right ear had worse responses than those with HL in the left ear[20].

In the sound localization test it was verified that the HLG had lower scores than the GWHL, and the mean correct answers of this group was lower than the normality criterion in this test (above four correct answers)[9]. Moreover, the comparison between groups showed difference. In this test, the ear affected by the HL did not influence the responses. Our finding agrees with previous studies that observed alterations in sound localization in individuals with unilateral HL[1,23,26,27]. The differences found between groups in the sound localization ability happen possibly because the binaural interaction (which does not occur in the HLG) strongly depends on the simultaneous use of both ears, the neural interaction that occurs with signals perceived by them both, and on how auditory information is processed. Such interactions contribute to locate sound sources in space[28].

Regarding the hearing ability of temporal ordering, the HLG had worse performance when compared to the GWHL.

In the RGDT, it was found that the GWHL presented mean thresholds 10 ms below in the final RGDT. In the HLG the thresholds are greater than 10 ms and lower than 15 ms, and the mean value of the HLGL (14.43 ms) was worse than the mean value of the HLGR (7.54 ms), which showed responses within normal limits. Thus, the HLG showed worse responses than the GWHL in the mean gap detection thresholds of the RGDT, however with no significant differences between groups. The HLG had a mean higher than the normality criterion established for the test, while the GWHL had a mean within the criterion[10].

Thus, it is observed that the HLG has greater difficulty in temporal processing, especially in the abilities of temporal ordering and temporal resolution. These data agree with a previous study, in which temporal resolution was assessed using the Gaps-in-Noise Test (GIN). The authors obtained worse results in patients with unilateral HL compared to individuals with normal hearing bilaterally. In this previous study, no differences were found between right and left ears[16]. Another similar study, however, observed that individuals with unilateral HL had significantly worse results than those with normal hearing. Additionally, this same study found a significant advantage for the right ear gap detection thresholds compared to the left, which was also observed in this study. The authors concluded that right and left ears have distinct temporal processing capabilities, possibly due to the specialization of brain hemispheres[7].

The loss in the ability of temporal resolution observed in the group with unilateral HL may be due to the fact that this hearing ability depends on two processes: the analysis of the temporal pattern that occurs in each frequency channel (inter--channel temporal analysis) and the comparison of temporal patterns of multiple audio channels activated at each moment (inter-channels temporal analysis). Such channels are related to the filtering characteristics of the peripheral auditory system. The cochlea behaves like a set of filters, which divides the components of a complex signal into "channels", tuned to different center frequencies[21]. Thus, the lack of response of the cochlea in one of the ears can influence temporal analysis of the sound.

CONCLUSION

In the presence of unilateral hearing loss difficulties in localization, closure, temporal resolution and temporal ordering are found. Subjects with unilateral hearing loss in the right ear have more complaints than those with hearing loss in the left ear. Individuals with loss in the left ear show more difficulties in closure, temporal resolution and temporal ordering.

RESUMO

Objetivo: Avaliar os comportamentos de resolução e ordenação temporal, localização sonora e fechamento auditivo e investigar queixas de dificuldades escolares, de comunicação e linguagem em indivíduos portadores de perda auditiva unilateral. **Métodos:** Participaram 26 indivíduos com idades entre 8 e 15 anos, divididos em dois grupos: Grupo com perda auditiva unilateral; e Grupo sem perda auditiva. Cada um deles foi constituído por 13 indivíduos que foram pareados conforme gênero, idade e escolaridade. Todos foram submetidos à anamnese, avaliação auditiva periférica e aos testes comportamentais de localização, memória sequencial, teste *Random Gap Detection* e ao teste de fala com ruído branco da avaliação do processamento auditivo. Foram utilizados testes estatísticos não paramétricos para comparar as repostas entre os grupos, considerando presença ou não da perda auditiva e o lado da orelha com perda. **Resultados:** O início da perda ocorreu na fase pré-escolar, com etiologias desconhecidas ou identificadas como meningite, traumas ou caxumba. A maior parte dos indivíduos relatou atraso no desenvolvimento de fala, linguagem e escolar, principalmente aqueles com perda à direita. O grupo com perda auditiva apresentou piores respostas nas habilidades de ordenação e resolução temporal, localização sonora e fechamento auditivo. Indivíduos com perda à esquerda mostraram resultados piores do que aqueles com perda à direita em todas as habilidades, exceto na localização sonora. **Conclusão:** Na presença da perda auditiva unilateral ocorrem dificuldades de localização, fechamento, resolução e ordenação temporal. Indivíduos com perda auditiva unilateral à direita apresentam mais queixas do que aqueles com perda à esquerda. Indivíduos com perda à esquerda mostram mais dificuldade de fechamento, resolução e ordenação temporal.

Descritores: Audição; Perda auditiva; Percepção auditiva; Testes auditivos; Linguagem

REFERENCES

1. Tharpe AM. Unilateral hearing loss in children: A mountain or a molehill? The Hearing Journal. 2007;60(7):10-16.
2. Bess FH, Dodd-Murphy J, Parker RA. Children with minimal sensorineural hearing loss: prevalence, educational performance, and functional status. Ear Hear.1998;19(5):339-54.
3. Feniman MR, Keith RW, Cunningham RF. Assessment of auditory processing in children with attention deficit hyperactivity disorder and language – based learning impairments. Disturb Comun. 1999;11(1):9-27.
4. Bellis TJ. Assessment and management of central auditory processing disorders: from science to practice. San Diego: Singular Publishing Group; 1996.
5. Eggermont JJ. Neural responses in primary auditory cortex mimic psycophysical, across- frequency-channel, gap detection thresholds. J Neurophysiol. 2000;84(3):1453-63.

6. Firszt JB, Ulmer JL, Gaggl W. Differential representation of speech sounds in the humam cerebral hemispheres. Anat Rec A Discov Mol Cell Evol Biol. 2006;288(4):345-57.
7. Sininger YS, de Bode S. Asymmetry of temporal processing in listeners with normal hearing and unilaterally deaf subjects. Ear Hear. 2008;29(2):228-38.
8. Silman S, Silverman CA. Auditory Diagnosis. San Diego: Academic Press; 1991.
9. Pereira LD. Processamento auditivo central: abordagem passo a passo. In: Pereira LD, Schochat E (org). Processamento auditivo central: Manual de avaliação. São Paulo: Lovise; 1997. p.49-60.
10. Keith RW. Random gap detection test. Auditec of Saint Louis. Missouri, USA; 2000.
11. Tharpe AM, Bess FH. Identification and management of children with minimal hearing loss. Int J Pediatr Otorhinolaryngol. 1991;21(1):41-50.
12. Bess F, Mckingley A, Murphy JD. Children with unilateral sensorineural hearing loss. Paediatric Audiological Medicine. 2002;3(4):249-313.
13. Lieu JE. Speech-language and educational consequences of unilateral hearing loss in children. Arch Otolaryngol Head Neck Surg. 2004;130(5):524-30.
14. Ito K. Can unilateral hearing loss be a handicap in learning? Arch Otolaryngol Head Neck Surg. 1998;124(12):1389-90.
15. Valente M, Valente M, Enrietto J, Layton K. Fitting strategies for patients with Unilateral hearing loss. In: Valente M. Strategies for selecting and verifying hearing aid fittings. 2a ed. New York: Thieme; 2002. p. 253-71.
16. Vieira, MR. Avaliação dos comportamentos auditivos de figura-fundo e de resolução temporal e da percepção de limitações de atividades comunicativas em crianças e adolescentes portadores de deficiência auditiva unilateral [tese]. São Paulo: Universidade Federal de São Paulo; 2010.
17. Oyler RF, Oyler AL, Matkin ND. Unilateral hearing loss: demographics and educational impact. Lang Speech Hear Serv Schools. 1988;19:201-10.
18. Nishihata R. Perda auditiva unilateral: Caracterização do desempenho auditivo, comunicativo e de linguagem [monografia]. São Paulo: Universidade Federal de São Paulo; 2005.
19. Wilmington D, Gray L, Jahrsdoerfer R. Binaural processing after corrected congenital unilateral conductive hearing loss. Hear Res. 1994;74(1-2):99-114.
20. Hartvig Jensen J, Johansen PA, Borre S. Unilateral sensorineural hearing loss in children and auditory performance with respect to right/left ear differences. Br J Audiol .1989;23(3):207-13.
21. Penhune VB, Zatorre RJ, MacDonald JD, Evans AC. Interhemispheric anatomical differences in human primary auditory cortex: probabilistic mapping and volume meansurement from magnetic ressonance scans. Cereb Cortex. 1996;6(5):661-72.
22. Ruscetta MN, Arjmand EM, Pratt SR. Speech recognition abilities in noise for children with severe-to-profound unilateral hearing impairment. Int J Pediatr Otorhinolaryngol. 2005;69(6):771-9.
23. Tharpe AM, Bess FH. Minimal, progressive, and fluctuating hearing losses in children. Characteristics, identification, and management. Pediatr Clin North Am. 1999;46(1):65-78.
24. Sargent EW, Herrmann B, Hollenbeak CS, Bankaitis AE. The minimum speech test battery in profound unilateral hearing loss. Otol Neurotol. 2001;22(4):480-6.
25. Welsh LW, Welsh JJ, Rosen LF, Dragonette JE. Functional impairments due to unilateral deafness. Ann Otol Rhinol Laryngol. 2004;113(12):987-93.
26. Humes LE, Allen SK, Bess FH. Horizontal sound localization skills of unilaterally hearing-impaired children. Audiology. 1980;19(6):508-18.
27. McKay S, Gravel JS, Tharpe AM. Amplification considerations for children with minimal or mild bilateral hearing loss and unilateral hearing loss. Trends Amplif. 2008;12(1):43-54.
28. Pinheiro MM, Pereira LD. Processamento auditivo em idosos: estudo da interação por meio de testes com estímulos verbais e não verbais. Rev Bras Otorrinolaringol. 2004;70(2): 209-14.

Appendix 1. Questionnaire on auditory, communicative and language performances

Unilateral hearing loss

Date of assessment:___/___/___

Name: _____ Age: _____

Date of birth:___/___/___ Sex: _____

Address:_____

Telephone: _____ Message:_____

Level of education: _____ Grade: _____

Maternal education: _____

Responsible: _____

1. Risk factors for hearing*	Yes	No			
a. Family history/inbreeding	( )	( )	i. Mechanical ventilation (> 5 days)	( )	( )
b. Congenital infection	( )	( )	j. Syndrome	( )	( )
c. Craniofacial anomaly	( )	( )	k Alcohol/drugs use	( )	( )
d. Weight <1500/PIG	( )	( )	l. Ventricular hemorrhage degree ___	( )	( )
e. Hyperbilirubinemia/transfusion. Ex: blood	( )	( )	m. Incubator ___ Days	( )	( )
f. Ototoxic ( ) Amikacin ( ) Vancomycin	( )	( )	n. Neonatal seizures	( )	( )
g. Bacterial meningitis	( )	( )	o. Otitis media recurrent/persistent	( )	( )
h. Apgar 0/4 in 1st minute e 0/6 in 2nd minute	( )	( )	p. Head injury	( )	( )
			q. Suspected developmental delay of language and hearing	( )	( )

2. Classification of hearing loss: _____
3. Etiology of hearing loss:
( ) yes _____
( ) no
4. Age of the identification of the loss: _____
5. Hearing loss: ( ) stable ( ) progressive ( ) sudden
( ) floating ( ) others
6. Tinnitus ( ) Yes ( ) No
7. Earache ( ) Yes ( ) No
8. Dizziness ( ) Yes ( ) No
9. Use a hearing aid? ( ) Yes ( ) No
Brand _____ Type _____
10. Since when? _____
11. Well adapted? ( ) Yes ( ) No
12. Frequency of use of the apparatus _____
13. Like using the device? ( ) Yes ( ) No
14. Functional gain of the device _____
15. School ( ) public ( ) private
16. Repeated a grade? ( ) Yes ( ) No
Which?_____
17. Attended school support programs? ( ) Yes ( ) No
18. Presents behavioral/disciplinary problems? ( ) Yes ( ) No
School ( ) At home ( ) Others ( )
19. Development of speech ( ) Normal ( ) Late ( ) Others
20. Development of language ( ) Normal ( ) Late ( ) Others
21. Has attended speech-language therapy? ( ) Yes ( ) No
22. Difficulty in communicating:
( ) in group ( ) classroom
( ) silence ( ) localization
( ) telephone ( ) Others
23. How do you feel about hearing loss:
( ) irritation ( ) revolt
( ) nervous ( ) others
24. Losses due to loss:_____
_____

*Azevedo MF. Programa de prevenção e identificação precoce dos distúrbios da audição. In: Schochat E. Processamento auditivo. São Paulo: Lovise; 1996. p.75-105.