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## Association between language development and auditory processing disorders<sup>☆</sup>

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### Abstract

**Introduction:** It is crucial to understand the complex processing of acoustic stimuli along the auditory pathway; comprehension of this complex processing can facilitate our understanding of the processes that underlie normal and altered human communication.

**Aim:** To investigate the performance and lateralization effects on auditory processing assessment in children with specific language impairment (SLI), relating these findings to those obtained in children with auditory processing disorder (APD) and typical development (TD).

**Material and methods:** Prospective study. Seventy-five children, aged 6-12 years, were separated in three groups: 25 children with SLI, 25 children with APD, and 25 children with TD. All went through the following tests: speech-in-noise test, Dichotic Digit test and Pitch Pattern Sequencing test.

**Results:** The effects of lateralization were observed only in the SLI group, with the left ear presenting much lower scores than those presented to the right ear. The inter-group analysis has shown that in all tests children from APD and SLI groups had significantly poorer performance compared to TD group. Moreover, SLI group presented worse results than APD group.

**Conclusion:** This study has shown, in children with SLI, an inefficient processing of essential sound components and an effect of lateralization. These findings may indicate that neural processes (required for auditory processing) are different between auditory processing and speech disorders.

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### Associação entre transtornos no desenvolvimento de linguagem e processamento auditivo

### Resumo

**Introdução:** Entender como os estímulos acústicos são processados ao longo da via auditiva é fundamental para compreender os processos que subjazem à comunicação humana normal e alterada.

**Objetivo:** Investigar o desempenho e efeitos de lateralidade na avaliação do processamento auditivo em crianças com distúrbio específico de linguagem (DEL), comparando os resultados

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obtidos aos encontrados em crianças com transtorno de processamento auditivo (TPA) e desenvolvimento típico (DT).

**Material e método:** Estudo Prospectivo. 75 crianças (6-12 anos), divididas em três grupos (25 crianças com DEL, 25 crianças com TPA e 25 crianças em DT), foram submetidas aos seguintes testes: Teste de Figura com Ruído, Teste Dicótico de Dígitos e Teste de Padrão de Frequência.

**Resultado:** Os efeitos de lateralidade foram observados apenas no grupo DEL, sendo o desempenho na orelha esquerda inferior ao apresentado na orelha direita. Na comparação intergrupos, o desempenho dos grupos TPA e DEL foi significativamente inferior ao observado no grupo DT para todos os testes. Além disso, observamos nas crianças do grupo DEL um desempenho inferior às do grupo TPA.

**Conclusão:** Este estudo constatou o processamento ineficiente de componentes cruciais de sons e o efeito de lateralidade em crianças com DEL. Esses achados evidenciam que os processos neurais que subjazem ao processamento auditivo são diferentes entre alterações de processamento auditivo e alterações de fala.

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## Introduction

About 7% of children have significant difficulty in functional language (receptive and/or expressive language disorders) for no apparent reason. In other words, these children have language alteration in the absence of hearing loss, changes in cognitive development, speech motor development impairment, pervasive developmental disorders and acquired sensorineural changes and syndromes and in neurological lesions.<sup>1,2</sup> This type of language disorder has been defined in most studies as specific language impairment (SLI).

Despite nearly a century of research, investigators have not reached a consensus on the physiological basis of causation of this disorder involving language development yet.

One possible theory suggests that one of the reasons for the occurrence of specific language impairment is related to changes in abilities to process sounds and to abnormalities in the neural coding of auditory information,<sup>3,4</sup> contributing to changes in the perception of critical acoustic cues contained in the speech signals.

The basic idea is as follows: the perception of those short, quick acoustic signals, such as speech sounds, is related to the ability to perceive and process rapid changes of spectral characteristics along the auditory pathway, within a time interval in the order of milliseconds, this being an essential process for the development of language. Thus, it can be said that the auditory perception is the result of the auditory signal processing. When a change occurs in this auditory processing, hence an instability in the representation of speech sounds (phonemes), this also occurs in the brain. This instability of the representation of speech sounds can lead to a difficulty in understanding the speech of other people, and also limits the ability to acquire the phonological, syntactic and semantic elements of language.<sup>5,6</sup>

Although the presence of alterations in auditory processing in individuals with SLI is supported by many studies, this theory is not universally accepted, since the results of other studies have failed to find evidence of changes in auditory processing in children with SLI<sup>7-9</sup> and, consequently, the etiological causes of disorders in language development remains controversial.

From the previously established relationships between the coding of speech and language skills, we intend to study the auditory processing and possible effects of laterality in children with SLI, relating them to these outcomes found in children with auditory processing disorder (APD) and with typical development (TD), through behavioral measures. The hypothesis is that the difficulties in speech processing are directly related to a deficit in auditory processing.

We hope this study will provide new information on the central auditory functioning in children with SLI, allowing a better understanding of this disorder and more appropriate and effective therapeutic interventions.

## Material and method

This study was approved by the Ethics Committee under Protocol 1049/07. The children's parents or guardians were instructed about the procedures of the study and signed a term of free and informed consent.

## Cases

Seventy-five children, ranging from 6-12 years, were evaluated. All subjects evaluated had auditory pure tone thresholds within the normal range ( $\leq 15$  dB HL) for the studied frequencies (500-4000 Hz), speech recognition scores  $\geq 88\%$ , normal tympanometric measures, and absence of neurological, cognitive or psychiatric disorders. If changes regarding the hearing, neurological, cognitive and psychiatric aspects were found, the individuals were excluded from the study and referred to specialized service.

The subjects were divided into three groups:

a. Typical development (TD Group): 25 children with typical development, according to information obtained through interviews with these children's parents or guardians and teachers, and with no school problems or speech and language problems. In addition, these children had normal performance in APD evaluation.

b. Auditory processing disorder (APD Group): 25 children diagnosed with APD using criteria established by the Ameri-

can Speech-Language-Hearing Association (ASHA), i.e., performance below normal for their age on at least two tests of the Hearing Processing Evaluation battery. The minimum assessment battery applied in this group was composed of temporal processing and monotic and dichotic hearing tests.

c. Specific language impairment (SLI Group): 25 children diagnosed with SLI using international reference criteria,<sup>1</sup> providing at least an average intellectual level in an intellectual assessment using the Raven Coloured Progressive Matrices test.<sup>10</sup>

## Procedures

After the selection of children, behavioral tests that assess central auditory processing were performed.<sup>11</sup> a) Monotic test - Speech-in-noise test - used to assess the ability of auditory closure. This test consists of a list of 10 monosyllabic words by ear, totalling 20 verbal stimuli, presented at a level of intensity of 40 dB HL above the SRT obtained in the speech test. The signal/noise ratio used was + 20 dB HL, i.e., the sign represented by monosyllabic words was 20 dB HL above the noise, and the child was instructed not to pay attention to the noise, pointing the figures corresponding to the words that were heard. This procedure was performed in both ears; b) Dichotic test - dichotic digit test - used to assess the figure-background hearing ability and binaural integration for linguistic sounds. Two numbers were presented simultaneously in pairs in each ear, and the child was instructed to repeat both pairs immediately after their presentation. In total, 20 pairs of numbers per ear, totaling 40 verbal stimuli, were presented at an intensity level of 50 dB HL above the SRT obtained in the speech test. The number of digits correctly repeated was converted to a percentage of correct answers (i.e. hits); c) Auditory temporal processing test - pattern of frequency test (PFT) - used to assess the ability of temporal ordering and inter-hemispheric transfer. In this test, the child was instructed to listen carefully to three stimuli and to respond orally to the order in which the sounds came. If the stimulus was acute, the child was instructed to respond with an acute voice, and if the stimulus was deep, the child was asked to respond with a deep voice. In the end, 20 sequences of three stimuli were performed, and the number of correct sequences was converted to a percentage of hits.

The Speech-in-noise test and “dichotic digit” tests were used to verify aspects of laterality. Therefore, the right and left ears were evaluated separately. The “pattern of frequency” test, was used to evaluate temporal auditory processing and was presented binaurally (right and left ears simultaneously).

## Statistical analysis

To accomplish the stated objectives, the statistical method used attempted to compare groups in face of the performance in the evaluation of (central) auditory processing. This way, the descriptive analyses of children’s age and of results of the tests were carried out through the construction of tables with observed values from descriptive statistics: mean, standard deviation, minimum, median and maxi-

mum. To compare the means of the tests in the three groups, and in the two ears evaluated, techniques of analysis of variance (ANOVA) and of analysis of variance with repeated measures (ANOVA repeated measure), respectively, were applied. The values considered statistically significant were marked with an asterisk (\*) when  $\leq 0.05$ , with two asterisks (\*\*) if  $\leq 0.01$ , and with three asterisks (\*\*\*) when  $\leq 0.001$ . The sign # was used to show a trend towards significance.

## Results

The subjects’ age had a similar distribution among the three groups; mean and standard deviation of  $8.80 \pm 2.08$  for TD,  $8.72 \pm 1.67$  APD and  $7.84 \pm 1.77$  SLI were found. By ANOVA, there was no statistically significant difference among the mean ages [F (2,72) = 2.07,  $p = 0.13$ ].

Table 1 shows the descriptive statistics of data obtained by the three groups in the “figure with noise” test. The mean percentage of hits in the left ear was smaller than the mean percentage in the right ear in APD(C) and DEL groups. However, this effect of laterality was statistically significant only for SLI group.

In comparing the hits averaged in the “figure with noise” test, we observed statistically significant differences between groups for both the right ear [F (2,72) = 10.84,  $p < 0.001^{***}$ ] and for the left ear [F (2,72) = 15.76,  $p < 0.001^{***}$ ]. Through the Tukey’s *post-hoc* test, we observed that, for the right ear, this significance lies only in comparisons between TD and the other two groups. In other words, we could observe that the mean of total hits in the TD group was higher than in the APD ( $p = 0.02^*$ ) and SLI ( $p < 0.001^{***}$ ) groups. As for the left ear, the DT group averaged more hits, with a statistically significant difference when compared to APD ( $p = 0.01^{**}$ ) and SLI ( $p < 0.001^{***}$ ) groups; in addition, the APD group had a better performance than DEL ( $p = 0.01^{**}$ ) group.

Similarly for the “dichotic digit” test, comparing the hits averaged, we observed statistically significant differences between groups for both the right ear [F (2,72) = 11.44,  $p < 0.001$ ] and for the left ear [F (2,72) = 21.75,  $p < 0.001$ ]. Through the Tukey’s *post-hoc* test, we noted that, for the right ear, that significance lies only in comparisons between TD and APD ( $0.002^{**}$ ) and TD and SLI ( $p < 0.001^{***}$ ). As for the left ear, in a situation similar to what was observed with the “figure with noise” test; the DT group also averaged more hits, with a statistically significant difference when compared to TPA ( $p < 0.001^{***}$ ) and DEL ( $p < 0.001^{***}$ ) groups; in addition, the TPA group performed better than the DEL ( $p = 0.04^*$ ) group.

Then, we compared the results obtained in PFT in these three groups. It should be noted that the percentages presented are the result of the use of the test in binaural form.

In Table 2 the descriptive statistics of data obtained by the three groups in the pattern of frequency test are listed.

Comparing the mean percentages of correct answers for the PFT obtained in the three groups, statistically significant differences were detected between the groups [F (2,72) = 24.71,  $p < 0.001^{***}$ ] (Table 2), and the mean percentage obtained in DT group was superior to those obtained by SLI and APD groups (Table 3).

**Table 1** Descriptive statistics for the percentage of correct answers on the figure with noise test and on dichotic digit test in the three groups, by ear.

			ANOVA						
			Mean	SD	Minim	Median	Maximum	F	P value
Figure with noise test	TD	RE	98.40	3.74	90	100.00	100	1.00	0.36
		LE	98.80	3.31	90	100.00	100		
	APD	RE	92.00	9.12	70	90.00	100	1.50	0.23
		LE	90.00	10.00	60	90.00	100		
	SLI	RE	87.20	11.00	70	90.00	100	6.33	0.01**
		LE	81.40	15.78	50	90.00	100		
Dichotic digit test	TD	RE	95.90	6.49	77.50	100.00	100.00	0.92	0.34
		LE	95.20	6.76	70.00	95.00	100.00		
	APD	RE	81.60	16.95	30.00	87.50	100.00	2.82	0.10
		LE	77.21	15.86	42.50	80.00	97.50		
	SLI	RE	77.60	16.64	25.00	80.00	97.50	15.79	0.001**
		LE	66.31	20.90	10.00	70.00	92.50		

\*\* p = 0.01.

**Table 2** Descriptive statistics of the percentage of correct answers to pattern of frequency test in the three groups.

	PFT				
	Mean	SD	Minimum	Median	Maximum
TD	89.60	9.28	65.00	90.00	100.00
APD	63.00	26.65	0.00	65.00	100.00
SLI	50.20	20.38	15.00	50.00	80.00

**Table 3** P values for comparison among the three groups in the pattern of frequency test.

	p value		
	TD vs. APD	TD vs. SLI	APD vs. SLI
Pattern of frequency test	< 0.001***	< 0.001***	0.06 <sup>#</sup>

\*\*\* p &lt; 0.001.

<sup>#</sup> Trend towards significance.

## Discussion

The results of the behavioral evaluation of the (central) auditory processing showed that the performance obtained by APD(C) and SLI groups were worse when compared to the TD group. In other words, children with SLI, as well as children with APD, showed difficulties in speech comprehension skills in conditions of degraded hearing (noise and/or competitive speech) and difficulty in processing non-verbal stimuli (discrimination, ordination, binaural integration and inter-hemispheric transfer of acoustic stimuli presented), that could result in difficulties in the accurate perception of speech and thus compromise the integrity of speech processing and production.

These results seem to confirm our hypothesis, which is supported by many studies indicating that changes in (central) auditory processing coexist with language disorders.<sup>12</sup>

However, in addition to identifying a worse performance of SLI group relative to TD group, we also found that children with SLI performed worse than children with APD in the tests using verbal stimuli (Figure with Noise/Dichotic Digit tests). These results are relevant when we consider that it is precisely the SLI group, not the APD group, which has

a delay in language development, and that these children still have current difficulties regarding the expressive and/or receptive language.

In that the temporal processing is involved in each test used in this study to assess auditory processing, we raise two hypotheses. The first is related to studies of Tallal<sup>3,5</sup> who attributes abnormalities of temporal auditory processing for deficits or delays in the acquisition of language. According to his studies, changes in temporal processing result in compromises in the perception of phonemes and of other aspects of language and reading, which depend on a precise phonemic representation.

However, the Tallal hypothesis<sup>3,5</sup> has been questioned, because some studies have not confirmed those findings, increasing the controversy about the aetiology of SLI. Some studies using evoked potentials,<sup>9</sup> psychoacoustic tests,<sup>13</sup> and speech perception tests<sup>8</sup> showed children with language difficulties had adequate performance on tasks of discrimination and temporal processing of auditory stimuli.

The second hypothesis suggests the presence of other disabilities in children with SLI in addition to those responsible for the auditory processing. According to

Bishop et al.,<sup>7</sup> the language disorders are likely a result of multiple factors (including auditory processing, language processing and higher cognitive functions) that act synergistically. This would explain the fact that some children show changes in auditory processing and normal language development.

In the current study, the statistically significant differences between APD and SLI groups were not supported by the results of Ferguson et al.<sup>14</sup> and Miller and Wagstaff.<sup>15</sup> These researchers found no differences between APD and SLI groups for measures of language, communication, cognitive skills, and auditory processing skills, among others.

Despite this apparent controversy, it seems an indisputable fact that children with SLI have difficulty in their processing stimuli that are brief or presented rapidly,<sup>1</sup> and in frequency discrimination,<sup>16</sup> and have problems with both auditory processing and language.<sup>6</sup>

Another feature found only by the SLI group in our research was a poorer performance of the left ear compared to the right ear, both for monotic and for dichotic tests.

Hemispheric differences are evident in the normal processing of speech sounds,<sup>17</sup> and the model presented by Kimura<sup>18</sup> shows a right ear advantage over the left ear for speech sounds, presented in a dichotic way. This advantage occurs because the speech auditory stimuli, captured by the right ear, are directly processed in the left hemisphere (the main hemisphere responsible for speech processing), through the actions of the contralateral pathways. When the speech sounds are captured by the left ear, are primarily directed to the right hemisphere (RH) first, and later, via the corpus callosum, are processed in the left hemisphere.

This asymmetry between ears would be expected to decrease with increasing age; this is a likely marker of maturity and of hearing process improvement.<sup>19</sup>

Thus, we could suggest that the differences between the ears, found in our study considering only children with SLI, would be consistent with abnormalities in the transmission of auditory information from the non-dominant ear toward the dominant hemisphere for speech processing via corpus callosum,<sup>20</sup> possibly due to a maturational delay (less myelination in the immature brain), or to impairments in the auditory system.<sup>21</sup> According to Moncrieff,<sup>19</sup> the findings on the differences between right and left ears represent an important aspect related to the immaturity in dichotic hearing ability.

Another possible interpretation of our findings would be that children with SLI, actually exhibit a disadvantage of the left ear compared to the right ear rather than exhibit a right ear advantage.<sup>22</sup>

The deficit found in this study for the left ear in two behavioural tests, combined with the deficit in the task of temporal auditory processing manifested in the pattern of frequency test, seems consistent with the hypothesis of an impairment of the inter-hemispheric function of auditory information, this function being exercised by the corpus callosum, which is the main pathway of association between the cerebral hemispheres.<sup>23</sup>

We know that the advantages presented by whatever ear may reflect functional differences between the brain hemispheres. However, this concept has been described in the specialized literature by dichotic, but not by monotic, tasks. The first applications of tests using “speech with

noise”, performed by Sinha,<sup>24</sup> reported deficits in the ear contralateral to cortical lesions. Subsequent studies have shown, in the “speech with noise” test, contralateral hemisphere deficits with implications in the auditory cortex.<sup>25,26</sup> However, these are not affected by inter-hemispheric transfer (corpus callosum).

Considering the data obtained - greater deficit found in the left ear in the dichotic test - plus the abnormal performance in the left ear in the monotic test, it is suggested that there is an involvement of the right hemisphere (RH), or possibly of RH and of interhemispheric transfer.<sup>27</sup>

We must take into account - on the hypothesis of a possible change in RH - its role in language processing. Whitehouse and Bishop<sup>28</sup> found some evidence that children with SLI might have the function of language lateralized to RH.<sup>28</sup> That is, our findings could corroborate the important language deficit displayed by these children.

In face of the hypotheses presented, we can consider that the possible causes of asymmetry between ears, found only in children with SLI, may be related either to a maturational delay - especially in regard to the interhemispheric transmission (corpus callosum) - but also to an impairment in RH, which would hamper the efficient processing of spectral information contained in the speech stimuli.

Thus, our results suggest that the neural processes that underlie auditory processing disorders may differ between auditory and language processing change.

## Conclusion

In this study, children with SLI exhibited poorer performance on the auditory processing abilities compared to children with APD and TD. In addition, only children with SLI showed laterality effect, suggesting that difficulties with language processing found in these children are related to possible deficits in interhemispheric transmission and/or in auditory processing in the right hemisphere. Thus, these findings suggest that neural processes (required for auditory processing) are different for auditory and speech processing changes.

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## Conflicts of interest

The authors declare no conflicts of interest.

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