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Artigo Original

Neuronal plasticity of the auditory pathway in children with speech sound disorder: a study of Long-Latency Auditory Evoked Potentials

Plasticidade neuronal da via auditiva em crianças com transtorno dos sons da fala: estudo dos Potenciais Evocados Auditivos de Longa Latência

Amanda Cristina Luna[1]
Liliane Aparecida Fagundes Silva[1]
Tatiane Faria Barrozo[1]
Renata Aparecida Leite[1]
Haydée Fiszbein Wertzner[1]
Carla Gentile Matas[1]

Keywords

Speech Sound Disorder
Evoked Potentials, Auditory
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ABSTRACT

Purpose: To analyze the results of Long-latency Auditory Evoked Potentials (LLAEP) in children with Speech Sounds Disorder (SSD) after speech therapy. **Methods:** Longitudinal and prospective clinical study at 14 children with SSD, with ages ranging from five to seven years, of both genders. Were applied Picture Naming task and Imitation task, and from these tasks it was calculated the Percentage of Consonants Correct index. For an analysis of the LLAEP with speech stimulus and recorded the latency and amplitude values of P1, N1, P2, N2 and P3 components. Each child was evaluated in two different moments: initial evaluation and after 12 sessions of speech therapy. **Results:** It was observed that after twelve sessions of speech therapy the value of Percentage of Consonants Correct index increased, and a greater number of components were observed in the LLAEP records of children with SSD, as well as a statistically significant increase in the amplitude of the P3 component, demonstrating that anatomical and physiological changes occurred in the central auditory nervous system after intervention, resulting in improved of the LLAEP results. **Conclusion:** After speech therapy, improvement in the children's phonology was observed, and there was an increase in the number of components present in the LLAEP, as well as an increase in the amplitude of the P3 component, demonstrating that plasticity occurred in the auditory pathway during these three months of therapeutic intervention.

Descritores

Transtorno Fonológico
Potenciais Evocados Auditivos
Plasticidade Neuronal
Audição
Criança

RESUMO

Objetivo: Avaliar os achados dos Potenciais Evocados Auditivos de Longa Latência (PEALL) em crianças com Transtorno dos Sons na Fala (TSF) após terapia fonoaudiológica. **Método:** Estudo clínico longitudinal e prospectivo em um grupo de 14 crianças com TSF, de cinco a sete anos de idade, de ambos os sexos. Foram aplicadas as provas de Nomeação de Figuras e Imitação de palavras, para as quais foi calculado o índice de gravidade Porcentagem de Consoantes Corretas. Foram registrados os PEALL com estímulo de fala e foram analisados os valores de latência e amplitude dos componentes P1, N1, P2, N2 e P3. Cada criança foi avaliada em dois diferentes momentos: avaliação inicial e após 12 sessões de terapia fonoaudiológica. **Resultados:** Os resultados mostraram que após terapia fonoaudiológica, o valor do índice de gravidade Porcentagem de Consoantes Corretas aumentou e um maior número de componentes foi observado nos registros dos PEALL nas crianças com TSF. Também foi observado um aumento estatisticamente significativo na amplitude do componente P3, demostrando que modificações anatomofisiológicas ocorreram no sistema nervoso auditivo central após intervenção, proporcionando melhora nos resultados dos PEALL. **Conclusão:** Após terapia fonoaudiológica, foi observada melhora no desempenho fonológico das crianças, aumento no número de componentes presentes nos PEALL, bem como aumento na amplitude do componente P3, demonstrando que ocorreu plasticidade na via auditiva após um curto período de intervenção fonoaudiológica.

Correspondence address:
Liliane Aparecida Fagundes Silva
Departamento de Fisioterapia, Fonoaudiologia e Terapia Ocupacional, Faculdade de Medicina, Universidade de São Paulo – USP
R. Cipotânea, 51, Cidade Universitária, São Paulo (SP), Brasil, CEP: 05360-160.
E-mail: liliane.a.fagundes@gmail.com

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Study conducted at Departamento de Fisioterapia, Fonoaudiologia e Terapia Ocupacional, Faculdade de Medicina, Universidade de São Paulo – USP - São Paulo (SP), Brasil.

[1] Departamento de Fisioterapia, Fonoaudiologia e Terapia Ocupacional, Faculdade de Medicina, Universidade de São Paulo – USP - São Paulo (SP), Brasil.

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INTRODUCTION

Speech sound disorder (SSD) is a disorder in which sounds are used incorrectly; it involves errors in production, perception or organization of sounds, which interferes in communication and in school and professional performance[1]. SSD is characterized by substitutions, omissions and/or distortions of speech sounds at inappropriate ages, with variable severity, and simplifications of phonological rules may generate a variable degree of speech unintelligibility[2]. Thus, the difficulty present in SSD may reflect in a collapse of phonemic contrasts, which may affect the meaning of the message[3].

Another important point worth noting is the interaction among the three processes involved in speech: auditory perception, cognitive-linguistic organization and motor speech[4]. When one of these processes is affected, the other two will also be[5]. It is known that for the appropriate development of different linguistic systems, both the peripheral and central auditory pathways must work properly[6].

The long-latency auditory evoked potential (LLAEP) is an objective method capable of reflecting neuronal activity in terms of attention, discrimination, memory, auditory integration and decision-making abilities, which are important requirements for the appropriate development of language[7,8]. It is the generation of positive and negative waves resulting from the neuroelectric activity of the thalamic and cortical auditory pathways, which appear between 50 and 500 ms after sound stimulation. The components may be defined according to the time of appearance and polarity of the wave, such as P1, N1, P2, N2 and P3[9]. According to the specialized literature, children with SSD may present alterations in latencies and amplitudes of LLAEP components[10-13], and the component that seems to most suffer from interference is P3[10].

The LLAEP has been described as an important instrument with clinical applicability to monitor neurophysiological alterations in the central auditory nervous system (CANS) (more specifically in the thalamo-cortical regions) after therapeutic intervention in several populations, such as in auditory processing disorders[14], cochlear implantation[15], language disorders[16], among others. Such changes may be visualized by means of morphology, presence and absence of response, and the latency and amplitude values of the LLAEP components[17].

Studies analyzing the effect of speech-language therapy on SSD are still scarce, and single-case studies predominate. Most of these studies are carried out with a limited number of sessions, generally 12, because it is the number the literature suggests as allowing the observation of alterations in children's performance[18]. In SSD, only two published studies evaluated alterations by the LLAEP, using tone burst stimulus in children with SSD after three months of speech-language therapy. After the intervention, an increase in the amplitude of the P3 component and decrease in the latencies of the P2 and P3 components were observed[10,11].

Several types of sound stimuli may be used to generate the electrophysiological response to the LLAEP, as the characteristics of the frequency spectrum differ among them. Verbal stimuli comprise a more complex spectro-temporal structure than non-verbal stimuli and require a greater neural synchrony to process the acoustic information[19].

Considering that the type of acoustic stimulus can directly influence the LLAEP responses and that SSD is a linguistic difficulty, it is important to evaluate neuronal plasticity after therapeutic intervention using speech stimuli. This owes to the fact that this is a stimulus with higher acoustic complexity, which, consequently, requires more time to be codified and processed by the auditory cortex.

Thus, the hypothesis of the present study is that children with SSD show improvement in the LLAEP responses after speech therapy intervention. Therefore, the present study aimed to analyze the LLAEP findings in children with SSD after speech therapy.

METHODS

This is a clinical, prospective and longitudinal study approved by the Ethics Committee of the research institution under number 423/15 carried out in children with SSD referred by the pelo Laboratório de Investigação Fonoaudiológica em Fonologia da Faculdade de Medicina da Universidade de São Paulo (FMUSP), where the study was carried out.

The diagnosis of SSD was performed in the aforementioned laboratory from which the children were referred for the study by means of phonology tests complemented with other tests that evaluated articulatory rate, speech inconsistency, phonological awareness, orofacial motricity, among other factors[1,5].

In order to take part in this study, the children were required to: be between five and seven years and 11 months of age; not present neurological complaints; have Brazilian Portuguese as their mother tongue, as must their parents; and not have undergone speech-language therapy previously.

In addition, the children were submitted to basic audiological evaluation in order to rule out any hearing impairment. For this purpose, a visual inspection of the external acoustic meatus was firstly carried out; then, acoustic immittance measures (Interacoustic equipment, model AT235) were conducted, in which the children were required to present a type A tympanometric curve[20] and the presence of contralateral and ipsilateral acoustic reflexes for all the frequencies assessed (0.5, 1, 2 and 4 kHz). A tonal and vocal audiometry was also carried out (Grason-Stadler audiometer, model GSI-61), in which the participants were required to present auditory thresholds below 20 dB HL in all of the frequencies evaluated (0.25 to 8 kHz)[21]. In addition, they were also required to present a Speech Recognition Threshold (SRT) equal to or up to 10 dB above the mean audibility thresholds of the frequencies of 0.5, 1 and 2 kHz of tonal audiometry and a Speech Recognition Percentage Index (SRPI) equal to or higher than 88% right, assessed in the intensity of 30 dB HL above the SRT[22].

Considering this, 14 children diagnosed with SSD aged between five and seven years, four females and ten males, met all the inclusion criteria and agreed to participate in the study. Their parents and/or guardians were informed about the objectives of the study and signed the Free Informed Consent Form (ICF).

In the present study, children were assessed by the phonology tests of the Child Language Test (ABFW)[23]. The ABFW phonology consists of the Naming Test (NT), which comprises 34 figures with 90 consonants, and the Imitation Test (IT), which comprises 39 words with 107 consonants. The tests were analyzed according to the parameters established by the ABFW.

From the ABFW phonology tests, the severity index Percentage of Consonants Correct (PCC)[24] was calculated, obtained by dividing the correct consonants by the total number of consonants in the sample. Omissions, substitutions and distortions of speech sounds were considered errors. The transcriptions of the phonology tests of all children were done by two researchers from one of the laboratories responsible for this study, with agreement equal to 90%.

The electrophysiological evaluation of hearing using LLAEP was carried out in an acoustically treated room with the child sitting comfortably in a reclining chair. To capture these potentials, the child's skin was first cleaned with abrasive paste, and the electrodes were superficially attached to the skin using electrolytic paste and microporous adhesive tape, following the International Electrode System (IES 10-20) standard[25]: active electrode placed on the vertex (Cz), ground electrode on the forehead (Fpz) and reference electrodes on the right and left mastoids (M2 and M1).

The LLAEP were elicited using the acoustic speech stimulus with the syllables /ba/ (frequent stimulus) and /da/ (rare stimulus). A total of 300 stimuli were elicited, with rare stimuli accounting for 15% and frequent stimuli for 85% of the total stimuli presented. The children were asked to remain alert and pay attention to the rare stimuli, which were presented in an oddball paradigm, among various frequent stimuli, and the children were asked to raise their hands whenever the rare stimulus appeared.

The stimuli were presented monaurally through an insertion headset at an intensity of 75 dB HL and a presentation speed of 1.1 stimuli per second, 1,000 ms inter-stimulus interval, 0.1 to 100 Hz band-pass filter, 1,000 gain, using an analysis window between 0 ms pre-stimulus and 500 ms post-stimulus.

The trace corresponding to the frequent stimulus was analyzed, as well as the latencies (in milliseconds – ms) of components P1, N1, P2 and N2, and the amplitudes P1-N1 and P2-N2 (in microVolts – μV). In the tracing resulting from the subtraction of the rare stimulus with the frequent stimulus, the P3 component was analyzed for its latency and amplitude.

The children underwent LLAEP and phonological evaluation, considering the PCC severity index, on two different occasions, as following: before the beginning of phonological stimulation (1st evaluation); and after 12 stimulation sessions (2nd evaluation). Three children did not attend the second phonological evaluation; thus, only the data from the first evaluation were considered.

The phonological stimulation program was designed with the intention of exposing the child with SSD to all the phonological patterns of Brazilian Portuguese for a short period of time in order to provide for a gradual adaptation of these patterns[26]. The program consists of a total of 12 sessions, one per week, lasting an average of 50 minutes each. Thus, every fortnight the child was exposed to the phonemes of a sound class in consonant + vowel syllables, such as plosives, fricatives, liquids and nasals, as well as in more complex syllables such as consonant + consonant + vowel and consonant + vowel + consonant. Regardless of the child's performance in the two hours of training for the phoneme classes, he/she was exposed to the next sequence of phonemes. This program was based on the cycles proposal[27] regarding gradual phonological acquisition and on gestural phonology, in which phonological representation is based on auditory perception and motor production of speech, allowing the acquisition of new patterns. Regardless of the phonological process used by the child, the program was consistently applied in the same way, with the same stimuli and activities.

The data obtained in the 1st and 2nd evaluations were tabulated, and a descriptive and inferential statistical analysis was performed using the Minitab 18 statistical software. Considering that the data did not follow normality, the Wilcoxon test was used to compare the results obtained between the two evaluations. It is worth noting that the LLAEP components that were absent were not considered in the inferential statistical analysis. The significance level adopted was 5%.

RESULTS

Initially, the sample was characterized according to age, gender and SSD severity by the PCC values before and after the speech-language therapy intervention (Table 1).

The results showed no statistical difference in the PCC results between the 1st and 2nd evaluations, both for naming and imitation tests. However, there was a trend towards statistical significance for naming (p-value = 0.080), and the PCC value in the 2nd evaluation was higher (Table 2). It is interesting to note that the standard deviation is high, and that the maximum and minimum values confirm this performance variability among individuals. However, we noticed that even the minimum and maximum values increased, and the maximum value reached its highest at the upper limit.

Regarding the LLAEP, we noticed a higher percentage of components present in the 2nd evaluation in both right and left ears (Table 3).

In addition, a descriptive analysis of the P1-N1, P2-N2 and P3 amplitudes was carried out, as well as the latency values of the components P1, N1, P2, N2 and P3 for each ear (Tables 4 and 5). Comparing the results between the 1st and 2nd evaluations, we noticed statistically significant differences in the left ear for the P3 amplitude, and the values were higher in the 2nd evaluation (Figure 1). On the other hand, comparing the results of the latency values between the 1st and 2nd evaluations, we did not observe a statistically significant difference in any of the components analyzed for both right and left ears (Figure 2).

Table 1. Sample characterization

Individuals	Gender	Age (years)	PCC			
			Imitation test		Naming test	
			1st Evaluation	2nd Evaluation	1st Evaluation	2nd Evaluation
AOS	M	6	89.72	92.52	85.56	87.78
AMC	M	7	86.92	99.07	87.78	96.67
CJC	M	5	83.18	84.11	74.44	83.33
DPF	M	7	72.90	79.44	64.44	80.00
KPOS	M	6	69.20	76.64	71.10	72.22
LGS	F	7	79.44	91.59	75.58	96.67
LROV	F	6	85.05	98.13	93.33	100.00
RJC	M	5	72.90	91.59	71.11	86.67
RRBS	M	5	87.85	94.39	86.67	91.11
AHS	M	7	53.20	52.44	41.10	44.12
AMA	F	5	91.50	-	90.00	-
LBAS	F	7	69.00	85.26	60.00	59.75
DS	M	6	91.58	-	90.00	-
NR	M	5	88.78	-	75.55	-

Caption: M = Male; F = Female; PCC = Percentage of Correct Consonants

Table 2. Descriptive and comparative analysis between the 1st and 2nd evaluations of the PCC, index of the ABFW phonology tests – imitation and naming tests

		Minimum	Maximum	Mean	Median	Standard deviation	Confidence Interval for the difference	W-value	*p*-value+
Imitation test	**1st Evaluation**	53.20	91.58	80.09	84.12	11.23	-14.95; 2.59	149.50	0.080#
	2nd Evaluation	52.44	99.07	85.93	91.59	13.24			
Naming test	**1st Evaluation**	41.10	93.33	76.19	95.57	14.39	-18.89; 5.55	161.00	0.261
	2nd Evaluation	44.12	100.00	81.67	86.67	17.09			

#*p*-value tends to statistical significance; +p-value obtained by Wilcoxon test

Table 3. Percentage of present responses with respect to components P1, N1, P2, N2 and P3 for each ear in both evaluations

		P1	N1	P2	N2	P3
Right ear	**1st Evaluation**	100%	93.3%	90.9%	100%	100%
	2nd Evaluation	100%	100%	100%	100%	100%
Left ear	**1st Evaluation**	100%	93.3%	86.6%	100%	100%
	2nd Evaluation	100%	100%	90.9%	100%	100%

Table 4. Descriptive analysis regarding the results of P1-N1, P2-N2 and P3 amplitudes for each ear in both evaluations

			Minimum	Maximum	Mean	Median	Standard Deviation	Confidence Interval
Right ear	**P1-N1**	**1st Eval.**	1.29	9.55	4.12	3.58	2.29	1.20
		2nd Eval.	3.60	8.16	5.42	5.27	1.38	0.72
	P2-N2	**1st Eval.**	1.85	9.86	6.09	6.53	2.85	1.49
		2nd Eval.	2.23	9.74	6.31	6.57	2.70	1.41
	P3	**1st Eval.**	6.85	13.61	11.17	11.26	1.76	0.92
		2nd Eval.	4.49	20.72	11.06	10.53	5.31	2.78
Left ear	**P1-N1**	**1st Eval.**	1.52	9.22	4.86	5.30	2.13	1.12
		2nd Eval.	2.05	7.70	4.47	4.50	1.29	0.67
	P2-N2	**1st Eval.**	0.80	11.20	3.25	3.24	3.10	1.62
		2nd Eval.	2.83	11.20	5.85	6.61	2.44	1.27
	P3	**1st Eval.**	4.89	15.58	10.21	9.58	2.75	1.44
		2nd Eval.	6.89	25.98	14.55	13.22	5.67	3.07

Caption: 1st Eval. = 1st Evaluation; 2nd Eval. = 2nd Evaluation. Descriptive Analysis

Table 5. Descriptive analysis regarding the results of P1, N1, P2, N2 and P3 latencies for each ear in both evaluations

			Minimum	Maximum	Mean	Median	Standard Deviation	Confidence Interval
Right ear	**P1**	**1st Eval.**	79	125	99.21	93.5	15.19	8.46
		2nd Eval.	64	122	93.00	92.5	16.36	7.98
	N1	**1st Eval.**	121	171	149.07	150.0	15.68	7.89
		2nd Eval.	118	169	147.40	153.0	16.89	8.62
	P2	**1st Eval.**	174	224	195.07	189.0	13.90	5.78
		2nd Eval.	149	234	197.00	200.5	20.52	10.08
	N2	**1st Eval.**	223	291	261.42	265.00	20.05	12.82
		2nd Eval.	238	294	265.10	266.5	16.17	8.33
	P3	**1st Eval.**	277	415	329.28	320.0	41.67	21.01
		2nd Eval.	279	391	321.70	319.5	32.10	15.76
Left ear	**P1**	**1st Eval.**	81	115	98.50	100.0	10.80	7.26
		2nd Eval.	87	109	98.80	100.5	8.17	4.42
	N1	**1st Eval.**	139	183	154.61	154.0	12.35	10.24
		2nd Eval.	128	167	150.20	149.0	11.91	6.74
	P2	**1st Eval.**	176	239	203.25	200.0	19.56	10.82
		2nd Eval.	170	238	198.11	193.0	21.13	12.41
	N2	**1st Eval.**	203	281	248.57	258.5	24.36	11.98
		2nd Eval.	220	280	249.90	250.5	22.05	10.78
	P3	**1st Eval.**	279	431	346.07	347.0	44.10	21.56
		2nd Eval.	272	391	318.40	318.0	29.52	17.73

Caption: 1st Eval. = 1st Evaluation; 2nd Eval. = 2nd Evaluation. Descriptive Analysis
*p-value with statistical significance.

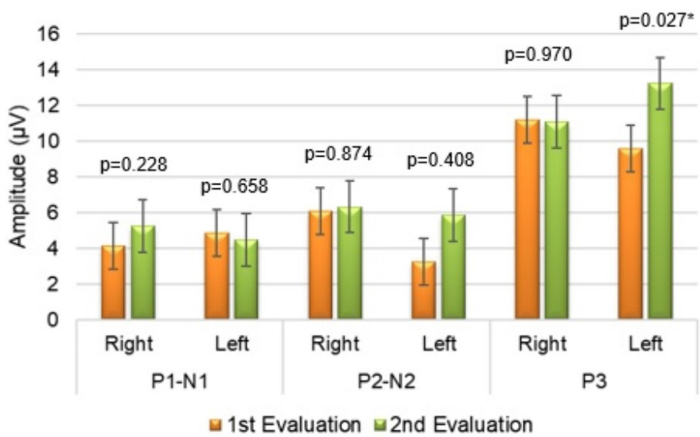

Figure 1. Comparison of amplitude values in microvolts of LLAEP components P1-N1, P2-N2 and P3 for each ear between the two evaluations

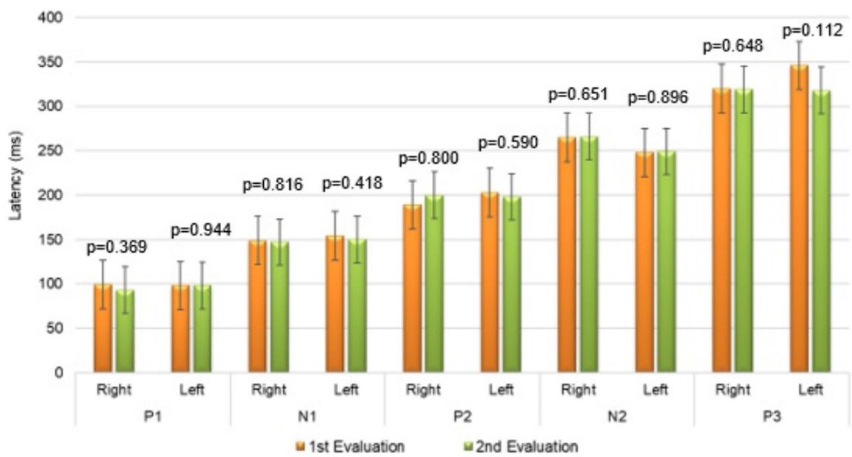

Figure 2. Comparison of latency values regarding LLAEP components P1, N1, P2, N2 and P3 for each ear between the two evaluations

DISCUSSION

This study aimed to analyze the LLAEP findings in children with SSD after speech-language therapy, since this procedure has been shown to be an important clinical resource capable of assessing the functional conditions as well as the evolution and limits of neuronal plasticity after intervention[17].

The phonological evaluation in the present study suggested that children performed better in the ABFW Naming and Imitation tests after stimulation. Although heterogeneity among the subjects regarding the severity of their SSD was observed in the minimum and maximum values of the PCC, it was noteworthy that the children showed evolution, and some of them reached the maximum scores (100%).

Considering that the phonological results showed a reduction in the severity of SSD after 12 intervention sessions, the results obtained in the LLAEP were also able to indicate improvement in the processing of sound information after the therapeutic process.

In the present study, we noticed a significant increase in the presence of LLAEP components with speech stimulus in the right and left ears after the speech-language therapy intervention. We did not find studies in the literature consulted that assessed neuronal plasticity analyzing the emergence of the LLAEP components observed in children with SSD.

It is known that the therapeutic stimulation enables CANS maturation owing to neuronal plasticity, causing a structural reorganization and/or functioning of the CANS, which allows the gradual appearance of LLAEP components[11,28,29]. Thus, the appearance of new components in LLAEP tracings after speech-language therapy objectively demonstrates the changes in cortical structures after therapeutic intervention.

Moreover, in the present study we noticed a significant increase in the amplitude of the P3 component after three months of speech-language therapy. Such finding corroborates that obtained in another study that also analyzed the LLAEP after three months of speech-language therapy in children with SSD; the only difference found was an increase in the amplitude of the P3 component[10].

This component has also shown to be an important marker of the therapeutic evolution in other populations, and an increase in amplitude and decrease in latency of the P3 component has been observed after auditory training sessions, suggesting that this component seems to be sensitive to clinical changes after therapeutic intervention[30].

It is known that the P3 component is an endogenous component, i.e., it depends on the individual's active response, reflecting cortical processes regarding auditory discrimination and temporal auditory processing[4]. Therefore, the change visualized by the increased amplitude of the P3 component suggests greater ease in auditory discrimination tasks, which is an ability usually worked on at the beginning of the therapeutic process, since it is essential for differentiating discrete phonemic features, which is frequently impaired in children with phonological disorders.

It has been well established in the literature that, after therapeutic intervention, morphological and functional modifications occur, such as increase in the neurons responsive to acoustic stimuli, increase in dendritic branching and neuronal myelination, as well as better effectiveness in synaptic connections and synchronizations[15]. Thus, an increase in the amplitude of a given component indicates that a greater number of neuronal fibers are activated in the cortical regions of the CANS in response to sound stimulation[8].

With respect to latency values, no statistically significant differences were observed in any of the components after therapeutic intervention. Such result does not corroborate another study that observed a decrease in the latency of the P3 component after three months of speech-language therapy. This difference may have occurred because of the type of acoustic stimulus used for the LLAEP recording, which was different from the one used in the present study (speech x tone burst)[11].

It is known that the speech stimulus has a more complex acoustic spectrum and, thus, requires greater neural synchronization in the detection, encoding and decoding process. In addition, it involves the activity of other cortical regions of auditory association for processing verbal information. Thus, the maturation of central auditory pathways for processing verbal information requires a longer time of stimulation in order to show significant changes[19].

In the present study, a decrease in latency values was observed for most components, although this difference did not reach the established significance value. Thus, studies with a larger sample size are necessary to better clarify the findings of LLAEP in this population.

Several studies have described alterations in LLAEP in children with specific language disorders, emphasizing that this potential is capable of reflecting specific neural processing characteristics of sounds in these individuals[16]. Few studies have compared LLAEP results in children with SSD with those obtained in children with typical development aiming to observe specific differences in the processing of sound stimuli in this population.

Among these studies, we observed a lower amplitude of the components N2[12] and P3[10] and higher latencies of the components P2 and P3[11] in comparison with typical development. Indeed, another study indicated that children with SSD had higher latency values for the components N1 and P2 than the normality proposed in the literature[13]. This suggests that children with SSD present impairment in the attentional and non-attentional processing of detection, encoding and decoding of sound stimuli.

The present study was limited in that it did not have a control group to compare the results. However, the fact of being a longitudinal study highlights the importance of LLAEP analysis as a clinical tool to complement the behavioral assessment of children with SSD after speech therapy in order to measure the benefits of the therapeutic process.

CONCLUSION

After speech-language therapy, changes were observed in the central auditory pathway by an increase in the number of components present in LLAEP, as well as an increase in the amplitude of the P3 component, showing the neuronal plasticity which occurred in the auditory pathway throughout the 12 therapeutic intervention sessions.

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Author contributions

ACL and RAL were responsible for data collection, tabulation and analysis, as well as for writing the manuscript; LAFS and TFB were responsible for data tabulation and analysis, as well as for writing the manuscript; HFW and CGM were responsible for the study design and general guidance in developing the execution phases as well as for writing the manuscript.