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Acoustically controlled auditory training as an intervention option in central auditory processing disorder in severe/ profound unilateral hearing loss

Treinamento auditivo acusticamente controlado como opção de intervenção em transtorno do processamento auditivo central em perda auditiva unilateral severa/profunda

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ABSTRACT

Purpose: To verify the effectiveness of the auditory training acoustically controlled in people with central auditory processing disorders and unilateral hearing loss from severe to profound. **Methods:** 16 individuals between the age of 13 to 21 diagnosed with unilateral hearing loss from severe to profound and central auditory process disorder has participated in this study, individuals were divided into two groups, consisting of eight individuals each, paired by age, sex and education. Eight of them – Experimental Group - underwent an individual Acoustically Controlled Auditory Training program consisting of eight sessions accomplished once a week. The remaining individuals - Control Group – there were no intervention. At the end of eight weeks, both groups were reassessed for Long Latency Auditory Evoked Potential (P300), and altered hearing abilities on the Sound Localization test, Synthetic Sentence Identification, Speech in Noise and Random Gap Detection Test. **Results:** There were no influences of the hearing loss side in the initial assessment for any of the groups. In the final assessment there was an improvement in all abilities, decreased latency and increased amplitude in P300 only Experimental Group. Individuals with hearing loss on the right showed a greater increase in P300 amplitude. There were no changes in the Control Group. **Conclusion:** The acoustically controlled auditory training was effective because it allowed an improvement of the auditory abilities and a modification in the neurobiological activity in relation to the auditory processing speed. This option it is suggested for intervention in people with a central auditory processing disorder and hearing loss.

Keywords: Hearing; Unilateral hearing loss; Auditory perception; Evoked potentials, auditory; Rehabilitation

RESUMO

Objetivo: Verificar a efetividade do treinamento auditivo acusticamente controlado em pessoas com distúrbio do processamento auditivo central e perda auditiva unilateral de grau severo a profundo. **Métodos:** Participaram do estudo 16 indivíduos, de 13 a 21 anos de idade, diagnosticados com perda auditiva unilateral de grau severo a profundo e transtorno do processamento auditivo central, divididos em dois grupos, com oito indivíduos cada, pareados por idade, sexo e escolaridade: grupo estudo submetido ao programa de treinamento auditivo acusticamente controlado, em oito sessões, realizadas uma vez por semana; grupo comparação, que não foi submetido a nenhum tipo de intervenção. Ao final de oito semanas, os grupos foram reavaliados quanto ao potencial evocado auditivo de longa latência (P300) e quanto às habilidades auditivas alteradas, observadas nos testes Localização Sonora, Identificação de Sentenças Sintéticas, Fala no Ruído e *Randon Gap Detection Test*. **Resultados:** Não houve influências do lado da perda auditiva na avaliação inicial, para nenhum dos grupos. Na avaliação final, verificou-se, somente no grupo estudo, aprimoramento de todas as habilidades auditivas, diminuição da latência e aumento da amplitude no P300. Indivíduos com perda auditiva à direita apresentaram maior aumento da amplitude do P300. Não foram observadas modificações no grupo comparação. **Conclusão:** O treinamento auditivo acusticamente controlado foi eficaz, pois possibilitou o aprimoramento das habilidades auditivas e a modificação na atividade neurobiológica quanto à velocidade de processamento auditivo. Sugere-se essa opção de intervenção em pessoas com transtorno do processamento auditivo central e perda auditiva unilateral.

Palavras-chave: Audição; Perda auditiva unilateral; Percepção auditiva; Potenciais evocados auditivos; Reabilitação

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INTRODUCTION

For communication, it is necessary to have the ability to deal with the sound or abilities that go beyond what can be measured in the audiogram. The alteration in these abilities is related to the Central Auditory Processing Disorder (CAPD)[1]. Many studies have shown the co-occurrence of Unilateral Hearing Loss (UHL) from severe to profound, CAPD[2-6], language alterations[7,8] and communicative activity limitations[2].

Monoaural hearing causes damage to the physiological mechanism of binaural interaction, which favors Sound Localization (SL), due to Interaural Level Differences in time and intensity, binaural addition, and spatial masking release, with consequent improvement in speech understanding in noise[3-5]. Besides, sensory deprivation of the auditory cortex by the ipsilateral and contralateral pathways, caused by the decrease or absence of response of one of the ears, can affect the development of auditory abilities in these individuals[2-6,8]. These losses can explain the oral and written language changes often seen in children and adolescents with UHL[2,3,6-8].

At UHL, although the Cochlear Implant (CI) restores the functionality of binaural hearing, improving SL and speech comprehension in noise[9], its acceptance by the person with UHL does not always occur and adaptation can be slow[5]. Currently, the Brazilian Unified Health System (UHS) provides for individuals with UHL, the conventional hearing aid and the Contralateral Routing of Signal (CROS) adaptation system[10].Conventional hearing aid is poorly recommended by otorhinolaryngologists, as they offer few benefits to speech amplification, especially if the level of UHL is profound. Even for severe hearing losses, this device does not enable speech recognition in noise and improvement in SL due to the large asymmetry between the sides[11]. The CROS system has the advantage of speech detection on the side with UHL in silent situations and a better understanding of speech in noise, when speech is transmitted predominantly on the side without hearing loss. However, this device does not allow for improvement in the SL, an ability that these individuals present the most difficulty[12]. Probably, for this reason, the device is often not well accepted, not to mention the aesthetic issue related to the stigma of hearing loss due to the need to use two hearing aids, although the loss is only on one side[11,12].

Acoustically Controlled Auditory Training (ACAT) has been widely used in the rehabilitation of patients with CAPD, with or without hearing loss[13-15]. This is a set of conditions and/or tasks that provide increased synaptic activity and generate structural and functional modifications, called auditory plasticity[13,16].

The ACAT effectiveness is evaluated through behavioral auditory tests, which evaluate auditory skills[17], and by recording the electrical activity of the sound stimulus along with the Central Auditory Nervous System (CANS) through Auditory Evoked Potentials[18]. One of these is the Long-Latency Auditory Evoked Potentials (LLAEP) – P300, generated by the discrimination of a rare auditory stimulus, among other frequent ones, of the same modality and different physical characteristics. It is considered an endogenous potential, as it is predominantly influenced by events related to cognitive abilities, being applied as an instrument of investigation of information processing - coding, selection, memory and decision-making[18,19].

Several studies have utilized the P300 before and after ACAT and observed a decrease in latency and/or an increase in amplitude after auditory stimulation, demonstrating changes in the neurobiological activity of auditory processing[14,15].

Although research has concluded that in individuals with UHL alterations occur in different hearing abilities[2-6] until recently no studies have been found using an ACAT for the rehabilitation of hearing abilities in the ear without hearing loss. In a study[4] that proposed rehabilitation based on SL-only training, it was found that this ability improved, but did not reach normality.

Thus, an ACAT that makes the functioning of the CANS of unilateral listeners more efficient can minimize the communicative difficulties faced by people with UHL, besides offering better neural conditions in the adaptation of the CROS system or the CI in the ear with hearing loss, if there is this possibility

The objective of this study was to verify the effectiveness of the ACAT in people with altered auditory processing and unilateral severe to profound hearing loss.

METHODS

This is a longitudinal intervention clinical study approved by the institutional research ethics committee (n. 1,093,839). Before the beginning of the research, all participants, or their guardians, signed the Free and Informed Consent Term.

Included were individuals with unilateral severe to profound sensorineural hearing loss in one ear and, in the opposite ear, airway hearing thresholds ≤ 25 dBHL and ≤15 dBHL in the bone route, type A tympanometric curve, bilaterally, and CAPD diagnosed by at least two altered behavioral hearing tests in the ear without hearing loss. Individuals with self-declared neurological and/or psychological alterations were excluded from the sample.

16 individuals with UHL and CAPD participated. No sample calculation was performed, as the maximum number of participants that met the inclusion criteria was 17 during the research period. However, one of them presented alterations in only one auditory processing test. For this reason, this participant was excluded. Therefore, the number of participants was limited due to the convenience of the institution's availability during the research period.

The age range varied from 13 to 21 years, with ten males and six females. The UHL was observed on the right ear in seven individuals and on the left in nine. The participants were divided into two groups, eight individuals each, paired by age, gender, and education: Experimental Group – EG, submitted to the ACAT program for eight weeks, and Control Group - CG, which did not undergo any type of therapeutic intervention during the research period. The mean ages of EG and CG were 16.13 and 16.0 years, respectively.

The etiology of hearing loss varied between non-syndromic genetics (12.50%), hypoxia and prematurity (12.50%); infectious diseases (mumps and meningitis - 18.75%); post-infectious disease (cholesteatoma - 18.75%); trauma (18.75%) and unknown causes (31.25%). The average age of discovery of UHL was 5 years.

In this study, it opted for hearing loss pairing on the right and left in the EG. The hearing loss on the right occurred in four individuals from the EG and five from the CG, while on the left it occurred in four individuals from the EG and three from the CG.

Both groups were submitted to the Initial Evaluation (IE) and, after two months approximately, to the Final Evaluation (FE), both composed by the following set of tests:

Sound Location Test (SL), which followed Protocol 14, proposed by Pereira and Schochat[17], regarding the criteria of application and normality. It is known that this test is used to evaluate binaural hearing, however, it was chosen to verify the possibility of response change after ACAT.

Two special monotic hearing tests (Speech in Noise – SiN and Synthetic Sentences Identification- SSI) from the Compact Disc (CD) "Behavioral Auditory Tests for Evaluation of Central Auditory Processing"[17] and the CD Random Detection Gap Test - RGDT[20] were selected and were presented only in the ear without hearing loss. The SiN evaluated the auditory closing ability and followed the criteria proposed in Protocol 3 of Pereira and Schochat[17].For the evaluation of the figure-background ability, we used the SSI with an ipsilateral competitive message (ICM) and signal-to-noise ratio -10. The application and normality criteria of Protocol 6[17] were employed. Finally, the RGDT test, which assessed hearing ability for temporal resolution and followed the application and normality criteria proposed by Dias et al.[21]. To perform the tests described, the following were used: acoustic booth, GSI-61 Clinical Audiometer, Grason Stadler brand, Telephonics TDH-50 P headphones, calibrated according to ISO 389 standards, and Acer brand notebook, for the presentation of stimuli recorded on CDs.

For the registration of the P300, the equipment *Smart* EP USB Jr, of the brand *Intelligent Hearing System* was used, of two channels. The electrodes were positioned on the forehead (Fpz: ground electrode), cranial vertex (Cz: active electrode) and earlobe without hearing loss (A1 for left ear or A2 for right ear), following the International System 10-20[22]. Each electrode presented impedance ≤ 5 and interlectrodes difference ≤ 2 ohms. The participants were instructed to remain silent and mentally count the different (rare) stimuli that appeared randomly amid equal (frequent) stimuli. The stimuli were transmitted via ER-3A in-the-ear phones without hearing loss. The parameters for the acquisition of the P300 were: 300 tone burst stimuli, being 85% frequent (1 kHz) and 15% rare (2 kHz), presented at 70 dBHL, with a speed of 1.1 stimuli per second. After capturing the potentials, the components N1, P2, N2 and P3 were marked.

P3, the component utilized in this study, was considered the largest positive wave resulting from the subtraction between the wave referring to frequent stimuli and the wave of rare stimuli, located after the N1-P2-N2 complex, with latency around 300 milliseconds (ms)[18]. Then, its amplitude was measured, positioning the cursor on the positive peak and another on the negative valley of the previous wave (N2-P3), being measured in microvolt (μV). The waves were marked by the main author of the study and by another examiner, for confirmation, to avoid bias[19]. Latency values between 225 ms and 365 ms[18] were applied as reference. The amplitude values were described and analyzed comparatively to each other.

The Communication Activity Limitations (CAL) perception questionnaire[2] was applied to verify if there was a change in participants' perception before and after ACAT. This questionnaire consists of 13 questions, subdivided into three types of situation: noisy, quiet and sound location. Responses ranged from 0 (no limitation) to 100% (complete limitation), transmitted using the Visual Analog Scale (VAS) and classified according to the International Functionality Classification (IFC) at 0-4% = no limitation; 5-24% = slight; 25-49% = moderate; 50-95% = severe; 96-100% = complete limitation.

In EG, after the IE, the ACAT program was started, adapted to UHL, based on the conventional ACAT[23]. Eight sessions were held, lasting one hour and periodicity of one week, in an acoustic booth, with recorded stimuli[17,24-26], presented via notebook attached to a two-channel audiometer and headphones, stimulating the ear with normal peripheral hearing. Time processing and monotic listening were worked out with low redundancy tests

The sessions were organized in increasing order of complexity; the intensity of the main message was fixed (based on the average of the speech reception threshold) and the signal-to-noise ratio varied from positive to negative. The criterion for the change of complexity was ≥ 70% of hits; when the hits were ≤ 30%, one step was turned back[13]. The hearing ability of SL was trained with percussion and pure tone stimulation instruments, at different frequencies and intensities, in an acoustic cabin, with the use of loudspeaker boxes in the right, left front and back positions.

At the end of each session, a sheet of activities related to the hearing skills worked on that day was handed out, explained to the patient's guardian, so that they could be carried out at home. In the following session, the person in charge made a brief comment about the participant's performance regarding the activities.

Chart 1 summarizes the sessions with auditory skills, in the order they were stimulated, and the materials used.

Up to two consecutive absences, or three spaced absences, were allowed in the ACAT period. The absences were replaced in the following weeks and at the end of the program, all participants had eight sessions. None of them exceeded the limit of absences.

The Analysis of Variance (ANOVA) was used to observe the existence of an interaction effect among the studied variables. When there was interaction, (p-value <0.05) comparisons were made between the mean hits in the test, between the two moments for each group, and comparison of the means between the groups, for each moment, and verified the p-value through the Student's t-test. The significance level for all hypothesis tests was 0.05 (5%).

Chart 1. Brief description of the auditory skills and materials used in each acoustically controlled auditory training session in the experimental group

Sessions	Hearing skills worked	Materials used
1st	Auditory discrimination (frequency and duration) and sound location	CD Specific Hearing Training Program for Changes in Auditory Processing - Hearing Discrimination Training - Tracks 1 and 2 SL: (10-12 kHz) rattle 5
2nd	Figure - background (verbal sounds), temporal ordering (duration) and sound location	CD Exercises for Development of Auditory Processing Skills: SSI (ICM) S/N Relations: 0 and -10 - Tracks 1 and 3 CD Behavioral Auditory Tests for Evaluation of Central Auditory Processing: SDT melodic tone 3 and 4 sounds - Tracks 17 and 18 SL: 5-8 kHz (bell)
3rd	Figure-background (verbal sounds); temporal ordering (frequency) and sound location	CD Exercises for Development of Auditory Processing Skills: SSI (ICM) Relations S/N -10 and -15 - Tracks 2 and 3 CD Behavioral Auditory Tests for Evaluation of Central Auditory Processing: FPT (melodic tone 3 and 4 sounds) - Tracks 15 and 16 SL: 5-8 kHz/ 10-12 kHz (rattle and bell)
4th	Auditory closure and sound location	CD Sentence Lists in Portuguese: Presentation and Strategies of Application in Audiology - Tracks 1 and 2 SL: warble tone - 1 kHz (audiometer- free field presentation)
5th	Auditory closure and sound location	CD Behavioral Auditory Tests for Evaluation of Central Auditory Processing: Compressed Speech Test - Tracks 6 and 8 SL: warble tone - 2 kHz (audiometer - free field presentation)
6th	Figure-background (non-verbal sounds) and sound location	CD Exercises for Development of Auditory Processing Skills - Tracks 27 and 28 SL: warble tone - 3 kHz (audiometer - free field presentation)
7th	Temporal sorting (frequency) and sound location	CD Specific Hearing Training Program for Auditory Processing Changes - Training Frequency - pure tone (2 and 3 sounds) - Tracks 14 and 15 SL: warble tone - 4 kHz (audiometer)
8th	Time Resolution and Sound Location	CD Specific Hearing Training Program for Auditory Processing Changes - Training Temporal Resolution - Track 18 SL: warble tone - 6 kHz (audiometer)

Subtitle: CD: compact disc; SSI: Synthetic Sentences Identification; SDT: Standard Duration Test; FPT: Frequency Pattern Test; SL: Sound Location; ICM: Ipsilateral Competitive Message; S/N: Signal/Noise; kHz: kilohertz

RESULTS

No significant differences were found between the performance in behavioral tests of individuals with UHL on the right and the left, and therefore it was decided not to separate the variable "side of hearing loss".

In the comparison between EG and CG, in IE, no differences (p>0.05) were observed for any of the tests, indicating the homogeneity of the group before the intervention. In FE, a significant difference was observed between EG and CG for all tests: SL: p-value=0.002; SSI and SiN: p-value<0.001; RGDT: p-value=0.005. This indicates the change that the intervention produced in the EG after ACAT.

Tables 1 (EG) and 2 (CG) show the descriptive statistics and p-values in the comparison between IE and FE.

In the EG, there was a difference in performance between the initial and final evaluations, that is, the ATAC promoted a beneficial effect in this group (Table 1). In CG, there was no difference between IE and FE, indicating that there was no change in hearing behavior in the period, but the similarity in the test and retest (Table 2).

In IE, EG and CG presented average performance values, indicative of CAPD. In the FE, the individuals from the EG (Table 1) exposed mean performance values, with improvement and normalization for the SiN, SSI (ICM) and RGDT tests. The SL test improved, but not normalized.

From the inferential analysis, it could be concluded that there was no effect on the side of hearing loss on the mean latency at P300 (p-value=0.598). Thus, the analyses were carried out only by group and time. The mean latencies of both groups are within the normal range before and after ACAT, and in FE, the EG showed lower latencies (Table 3).

The amplitude analysis of the P300 showed an interaction effect between the side of the hearing loss and the groups (p-value=0.003). Therefore, the amplitude mean analysis was also carried out considering the "side of hearing loss" variable.

Only the EG showed a significant increase in amplitude in the P300, in the FE, being statistically significant for those with right hearing loss and with a tendency to significance for individuals with left hearing loss (Table 4).

The analysis of the answers to the CAL perception questionnaire showed that there was no perception of limitations in the quiet situation, in IE and FE, for any of the groups (p-value>0.999). In the SL situation, CG and EG presented CAL of a moderate degree in the IE, maintaining for CG, in the FE (p-value=0.988). For EG, in FE, the degree of CAL perception passed to slight and there was a difference with the tendency to significance between the two moments (p-value=0.079). In the noisy situation, it was verified that the two groups presented the perception of CAL of severe degree, in the IE and, for the CG, there was no significant difference between IE and FE (p-value=0.961). For the EG, it was possible to observe a modification in the degree of CAL perception to moderate and the difference between the moments was statistically significant (p-value< 0.001) (Figure 1).

Table 1. Descriptive statistics and *p*-value for comparing the results of the behavioral evaluation of auditory processing in the initial and final evaluations for the experimental group

	SL (n.° hits)		SiN (% hits)		SSI (% hits)		RGDT (threshold in ms)	
	IE	FE	IE	FE	IE	FE	IE	FE
Mean	2.75	3.37	61.50	75	61.25	83.75	11.06	6.66
SD	0.71	0.52	8.26	5.95	9.91	7.44	6.17	5.00
Minimum	2	3	48	64	50	70	5.00	3.50
Average	3	3	62	76	60	85	10.00	6.87
Maximum	4	4	72	84	80	90	25.00	10.00
n	8	8	8	8	8	8	8	8
***p*-value(t)**	0.021*		<0.001*		<0.001*		0.016*	

t: Student's t-test; *statistically significant

Subtitle: SL: Sound Location (normality - Pereira and Schochat[17]: ≥ 4 hits); n.º: number; %: percentage; SiN: Speech in Noise test (normality - Pereira and Schochat[17]: ≥ 70% hits-); SSI: Synthetic Sentences Identification (normality - Pereira and Schochat[17]: ≥ 70% hits); RGDT: Randon Gap Detection Test (normality - Dias et al.[21]: ≤ 10 ms); ms: milliseconds; IE: Initial Evaluation; FE: Final Evaluation; n: number of individuals; SD: Standard Deviation

Table 2. Descriptive statistics and *p*-value for comparing the results of the behavioral evaluation of auditory processing in the initial and final evaluations for the control group

	SL (n.° hits)		SiN (% hits)		SSI (% hits)		RGDT (threshold in ms)	
	IE	FE	IE	FE	IE	FE	IE	FE
Mean	2.50	2.50	61.50	62.50	58.75	58.75	11.69	11.84
SD	0.76	0.76	5.21	4.75	12.46	12.46	6.05	5.67
Minimum	2	2	52	56	40	40	4.75	4.75
Average	2	2	60	64	60	60	13.13	13.75
Maximum	4	4	68	68	80	80	20	18.75
n	8	8	8	8	8	8	8	8
***p*-value (t)**	>0.999		0.952		>0.999		0.999	

t: Student's t-test

Subtitle: SL: Sound Location (normality – Pereira and Schochat[17]: ≥ 4 hits); n.º: number; %: percentage; SiN: Speech in Noise test (normality - Pereira and Schochat[17]: ≥ 70% hits-); SSI: Synthetic Sentences Identification (normality - Pereira and Schochat[17]: ≥ 70% hits); RGDT: Randon Gap Detection Test (normality - Dias et al.[21]: ≤ 10 ms); ms: milliseconds; IE: Initial Evaluation; FE: Final Evaluation; n: number of individuals; SD: Standard Deviation

Table 3. Descriptive statistics of the latency of the Auditory Evoked Potential long latency - P300 (ms) in the initial and final evaluations and *p*-value calculated for comparison in each group

Group	Moment	n	Mean	SD	Minimum	Average	Maximum	*p*-value (t)
CG	**IE**	8	331.00	24.56	302	325.0	364	0.096
	FE	8	329.75	26.08	305	315.5	371	
EG	**IE**	8	342.50	24.05	317	332.0	389	**0.009***
	FE	8	321.88	8.46	310	321.0	334	

t: Student'st-test; *statistically significant

Subtitle: CG: Control Group; EG: Experimental Group; n: number of individuals; SD: Standard Deviation; IE: Initial Evaluation; FE: Final Evaluation; ms: milliseconds; (normality - McPherson[18]: 225 to 365 ms)

Table 4. Descriptive statistics of amplitude in long-latency Auditory Evoked Potential (- P300 (μV) in initial and final evaluations and *p*-value calculated for comparison in each group

Group	HL side	Moment	n	Mean	SD	Minimum	Average	Maximum	*p*-value (t)
CG	**RE**	**IE**	3	5.03	1.21	3.74	5.21	6.15	0.144
		FE	3	3.95	0.95	3.22	3.61	5.03	
	LE	**IE**	5	6.13	2.29	3.27	6.02	9.66	0.947
		FE	5	6.09	2.15	3.96	5.92	9.41	
EG	**RE**	**IE**	4	7.40	1.39	6.05	7.15	9.23	**<0.001***
		FE	4	12.11	0.93	11.20	12.11	13.01	
	LE	**IE**	4	7.57	3.59	3.44	7.36	12.13	**0.073#**
		FE	4	8.75	3.65	4.03	9.49	11.98	

t: Student's t-test; *statistically significant; #tendency to significance

Subtitle: CG: Control Group; EG: Experiment Group; HL: Hearing Loss; RE: Right Ear; LE: Left Ear; n: number of individuals; SD: Standard Deviation; IE: Initial Evaluation; FE: Final Evaluation; μV: microvolt

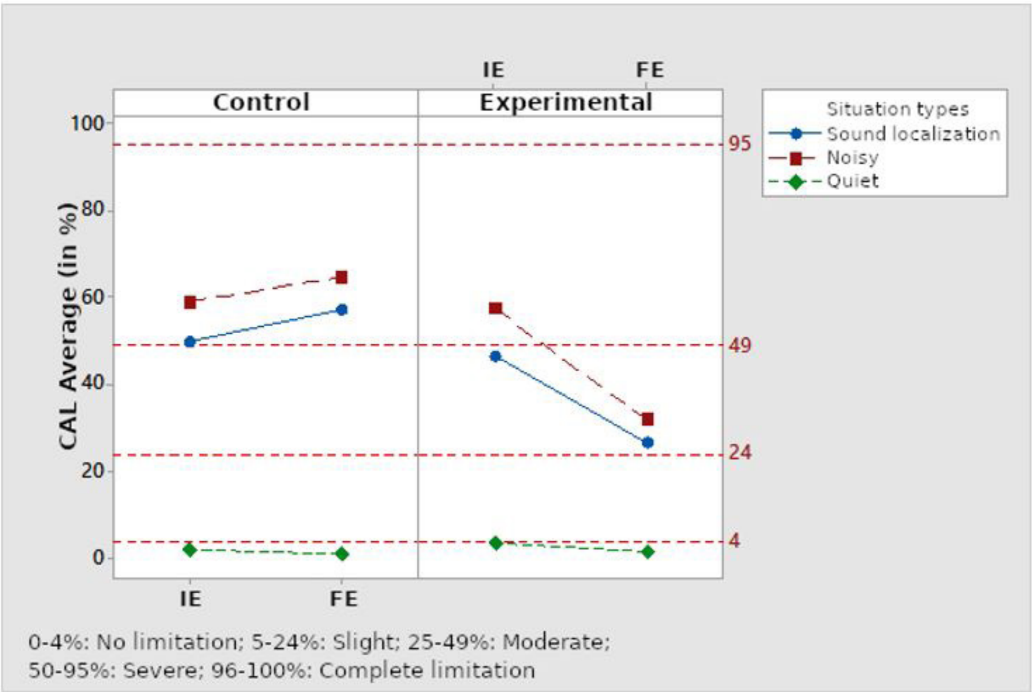

Figure 1. Average profiles of communicative activity limitations by moment, group and type of situation
Subtitle: CAL: Communication Activity limitation; IE: Initial evaluation; FE: Final evaluation; %: percentage

DISCUSSION

In this study, which aimed to verify the effectiveness of ACAT in people with altered auditory processing and UHL, groups of unilateral hearing individuals were selected and paired according to gender, age, and education, to seek a homogeneous sample. In behavioral hearing tests in IE, the performance was similar between the groups, since there was pairing concerning the CAPD.

The presence of CAPD in unilateral listeners reaffirms previous studies[2-6] and demonstrates the importance of follow-up of these individuals, particularly at school age, since these alterations can predict difficulties in oral and written language[3,7] and limitations of moderate to severe grade communicative activities[2].

Individuals with right and left UHL were included in the groups to check for possible influence on the side of hearing loss in behavioral tests and P300. Studies that evaluated the cortical functioning in individuals with UHL, using functional magnetic resonance imaging, suggested that there is a strengthening of the ipsilateral auditory pathways, which leads to induced cortical reorganization, especially when the hearing loss is on the left side. These studies have highlighted that neuroplasticity is more likely to occur in the right auditory cortex[27,28].

The purpose of this study was to present ACAT as an option for intervention in CAPD in people with severe to profound UHL, taking into account the scarcity of research on the subject. Until recently, there has only been one study with ACAT in severe to deep UHL, which stimulated only the hearing ability of SL[4]. The effectiveness of ACAT in improving hearing skills in bilateral normal peripheral hearing and CAPD[13,15] and bilateral hearing loss[14] has already been proven.

The limits of this research concern the small number of one-sided listeners with altered auditory processing and the failure to perform imaging examinations, such as magnetic resonance imaging, to check the conditions of the auditory system.

The objective of the EG formation was to verify the effectiveness of the ACAT program in approximately two months. The significant improvement observed in EG, FE and auditory processing suggests that the program was effective. This result has also been exposed in other studies that carried out ACAT in listeners without hearing loss and with CAPD[13,15] and in individuals with hearing loss of up to moderately severe degree, users of hearing aid[14].

A CG was formed to verify the reliability between test and retest, using the same procedures, and was confirmed. Furthermore, this finding shows that there was no modification of auditory neurodevelopment in the period in question.

The difficulty of SL in UHL, verified in this research, has already been observed in other studies[2-5]. In one of them[5], it became evident that unilateral listeners developed strategies to localize sound over the years, and the shorter the time of hearing loss, the greater the difficulty in localizing sound. It is believed that these strategies could have been potentiated if there had been specific auditory training for this

In the present study, the significant improvement in the EG's SL ability, in FE, without normalization of hearing ability, showed that some difficulty remained in the binaural processing, probably due to the high degree of the UHL, in which there is a reduction in the clues provided by the interaural differences of time and intensity[3-5]. The same fact was observed in a survey that performed the ACAT for SL with different stimuli[4]. In both studies, the UHL was severe to profound, which significantly reduces the response of an ear. For this reason, ACAT can improve the auditory function of SL in UHL, but not enough for the brain to precisely determine the origin of the sound.

In IE, the low performance observed in the SSI (ICM) and SiN tests, which evaluated the physiological mechanism of selective attention and the figure-background and closure abilities, respectively, has already been reported in previous studies, which evaluated individuals with UHL[2-6]. These changes may be justified by the decrease in intrinsic redundancy, due to the sensory deprivation necessary for adequate performance in these tests[3]. Normalization in the EG demonstrated that the ACAT performed with ear stimulation without hearing loss allows for the adequacy of these auditory abilities.

The improvement of these abilities after ACAT has already been verified in other studies with different populations[13-15] and is mainly due to the auditory plasticity that occurs after ACAT, which anatomic and functionally strengthens and modifies the auditory pathways responsible for conducting auditory information, leading to increased intrinsic redundancy of CANS[13,16].

The altered temporal resolution ability in UHL was verified, in this study, in IE and previous researches of the same research group[2,3] and differed from a study[29] whose temporal resolution was normal. A possible explanation for this difference may be the stimulation environment, socio-cultural differences and emotional significance of auditory experiences in each person with UHL, which affect the brain differently.

Studies have suggested that individuals with UHL present cortical reorganization, in which the ipsilateral pathways are more strengthened to compensate for sensory deprivation caused by the absence of responses from one of the ears[27,28]. The normalization of the EG temporal resolution, in FE, probably occurred due to the strengthening of the ipsilateral pathways and highlights the importance of significant acoustic experiences.

In this study, no significant differences in the behavioral evaluation of central auditory processing were observed among individuals with right or left hearing loss, similar to most studies in the specialized literature[2,4,5]. Few studies have verified this influence[3,6], and it was concluded that individuals with hearing loss on the right presented better responses in verbal tests. However, researches that evaluated the cortical functioning of people with UHL found that neuroplasticity is more likely to occur when the hearing loss is to the left[27,28].

The lack of consensus among studies on the effect of the hearing loss side on auditory processing suggests that neuroplasticity in UHL might also be influenced by socio-cultural factors that provide several significant auditory experiences.

In this research, the P300 of both groups showed that, in IE, the mean latency was within normal standards and amplitude showed high variability, as well as observed in individuals with normal bilateral hearing[15,18].

Although no studies are evaluating the P300 component in a UHL, there are two studies in the literature analyzing the latencies of components N1 and P150 in an LLAEP, in unilateral listeners, in which responses were also observed within the normality pattern[27,28]. Until recently, there are still no studies evaluating the P300 in individuals with UHL, before and after the ACAT.

The P300 analysis was used for comparison of the individual with CAPD and normal hearing thresholds[15] and also in people with hearing loss who use hearing aid[16], for comparison before and after an ACAT, to verify the efficiency of this intervention. These studies have shown neurobiological modifications regarding latency decrease and amplitude increase of this potential.

The significant decrease of the P300 latency observed in the EG, in the FE, indicates that there was neurobiological modification after the intervention and that the ACAT contributed to the increase of the information processing speed. The increase in amplitude in the EG indicates that the neural networks that the attentional system uses for the performance of the task were enlarged[13,16,18]. The difference observed between the ears, i.e., the increase in amplitude with statistical significance after ACAT, only in the group with right hearing loss, can be explained by the strengthening of the contralateral auditory pathways of the left ear, which favored the perception of pitch and the recognition of the acoustic outline by the right temporal lobe of auditory cortex[30].

The observed changes in latency and amplitude reflect the neuronal plasticity, which is considered the basis of speech-language therapy[13,15]. Additionally, long-term potentiation, related to memory and learning, which corresponds to the increase in synaptic transmission induced by intense and repeated activity[16], has been a relevant factor for the success of ACAT.

The perception of CAL observed in both groups, in IE, agrees with previous studies regarding SL and speech comprehension in noise[2-7], explained by the disadvantages of unilateral hearing[3-5]. As expected, difficulties did not occur in silent situations. It is hypothesized that, in this case, the brain was able to decode the message received by the ear with normal peripheral hearing. The decrease in CAL perception observed in the EG, associated with the improvement verified in behavioral and electrophysiological tests, evidences the efficacy of ACAT.

Although CI is considered one of the best options for rehabilitation in UHL[9], it is not always well accepted[5] or available, as it is not included in UHS procedures in Brazil for these individuals[10]. The CROS system, included in the UHL rehabilitation options, improves sound detection on the side of hearing loss; however, it does not assist in the hearing ability of SL and speech recognition in noise[12].

Based on the evidence shown in this study, it is suggested the evaluation of central auditory processing and an ACAT in UHL, if necessary, associated with the use of electronic devices for individual sound amplification, such as the CI or the CROS system, to improve communication processes.

CONCLUSION

Acoustically controlled auditory training was effective, as it enabled the improvement of auditory skills and the modification of neurobiological activity in terms of auditory processing speed. Based on the evidence shown in this study, this option for intervention in people with central auditory processing disorders and unilateral hearing loss is suggested. Therefore, auditory processing assessment and acoustically controlled auditory training should be included in the rehabilitation program for people with unilateral hearing loss.

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