REVISTA CEFAC
SPEECH, LANGUAGE, HEARING SCIENCES AND EDUCATION JOURNAL
Rev. CEFAC. 2017 Jan-Fev; 19(1):126-134 doi: 10.1590/1982-0216201719110916

Case reports

Acoustically controlled auditory training in an adult after traumatic brain injury

Treinamento auditivo acusticamente controlado em um indivíduo adulto após traumatismo cranioencefálico

Andrea Tortosa Marangoni Castan[1]
Cyntia Barbosa Laureano Luiz[2]
Daniela Gil[2]

[1] Universidade Federal de São Paulo – UNIFESP – São Paulo (SP), Brasil.
[2] Departamento de Fonoaudiologia - Universidade Federal de São Paulo – UNIFESP – São Paulo (SP), Brasil.

Work done in the Departamento de Fonoaudiologia, Universidade Federal de São Paulo – UNIFESP – São Paulo (SP), Brazil.

Financial support: Fundação de Amparo à Pesquisa do Estado de São Paulo FAPESP - process number 2010/04404-0.

Conflict of interest: non-existent

Received on: August 12, 2016
Accepted on: October 24, 2016

Mailing address:
Andrea Tortosa Marangoni Castan
R. Botucatu, 802, Vila Clementino
São Paulo (SP), Brasil
CEP: 04023-062
E-mail: andreatortosa@hotmail.com

ABSTRACT

Electrophysiological and behavioral assessment of auditory processing has been an important tool for the diagnosis and therapeutic monitoring in individuals after traumatic brain injury. In this case report, the patient underwent electrophysiological and behavioral assessment of auditory processing pre and post acoustically controlled auditory training (ACAT) and six months after the intervention. The ACAT was organized in eight sessions, focusing on the training of auditory abilities of temporal ordering, auditory closure and figure-ground. Post evaluation ACAT showed better results considering the processes of encoding, organization, and non-verbal. Electrophysiological evaluation showed improved morphology and shorter latencies in auditory brainstem response and higher amplitude of long latency auditory evoked potential (P300). During the reassessment six months after of the ACAT, stability and improved behavioral and electrophysiological evaluation were observed. Acoustically controlled auditory training proved to be effective in developing and refining different auditory abilities as demonstrated in electrophysiological and behavioral assessments of the central auditory processing and the benefits were stable long term.

Keywords: Hearing; Neuronal Plasticity; Rehabilitation; Brain Injuries

RESUMO

A avaliação eletrofisiológica e comportamental do processamento auditivo tem sido uma importante ferramenta para o diagnóstico e monitoramento terapêutico de indivíduos pós traumatismo cranioencefálico. No presente relato de caso o paciente foi submetido à avaliação eletrofisiológica e comportamental do processamento auditivo pré e pós treinamento auditivo acusticamente controlado (TAAC) e seis meses após a intervenção. O TAAC foi organizado em oito sessões, enfocando o treinamento das habilidades auditivas de ordenação temporal, fechamento auditivo e figura-fundo. Na avaliação pós TAAC foi observada melhora quanto aos processos gnósicos de codificação, organização e não verbal. Em relação à avaliação eletrofisiológica houve melhora na morfologia e na latência das ondas do potencial evocado auditivo de tronco encefálico e na amplitude do componente potencial evocado auditivo de longa latência (P300). Na reavaliação após 6 meses do TACC foi verificada estabilidade e melhora da avaliação comportamental e eletrofisiológica. O treinamento auditivo acusticamente controlado mostrou-se eficaz ao desenvolver e refinar diferentes habilidades auditivas como demonstrado na avaliação eletrofisiológica e comportamental do processamento auditivo e os benefícios mostraram-se estáveis no longo prazo.

Descritores: Audição; Plasticidade Neuronal; Reabilitação; Traumatismos Encefálicos

INTRODUCTION

Traumatic Brain Injury (TBI) is defined as any traumatic aggression that results in skull fracture, scalp injury, functional impairment of the meninges, encephalon or vessels. These lesions can be caused by the impact and movement of acceleration and deceleration of the brain within the cranial casing[1].

TBI lesions may result in central auditory deficits due to the connection with different areas, including cortical and subcortical hearing areas[2], being important the evaluation of short and long latency auditory evoked potentials, as well as central auditory processing[3,4]. In addition, an Intervention program, aimed at the quality of life of these patients from the point of view of hearing and language proves to be important.

In the first three months, especially in the first month, there is a spontaneous recovery after a brain injury, more specifically after TBI. After this period, the injured brain can modify and readapt itself through stimulation-induced neuronal plasticity, and the size, location and severity of the lesion being limiting factors in this process[5,6].

Acoustically controlled auditory training (ACAT) consists of a set of strategies used to enable or rehabilitate auditory perception, which assists in the linguistic and phonemic processing necessary for speech comprehension and maximizes the effects of plasticity of the central auditory nervous system[7].

Auditory evoked potentials provide important information for the diagnosis and may assist in the therapeutic monitoring of individuals after brain trauma, revealing changes in the neural activity related to the auditory experience provided by the ACAT. Due to its plasticity, central nervous system is able to reorganize as a consequence of stimulation, and thus, the latency and amplitude parameters can be modified in auditory evoked potentials, reflecting an objective measure of neural plasticity.

From the stated, the present study aims at verifying the effects of an acoustically controlled auditory training program in an adult after suffering brain trauma within a period up to six months after the intervention.

CASE PRESENTATION

This research was carried out in the University's outpatient clinics, after approval by the Research Ethics Committee of the Federal University of São Paulo (nº 0389/10) and the individual signed the Informed Consent Form before participating in the study.

A 22-year-old, right-handed male individual with auditory thresholds within normal range who had suffered severe head injury (initial Glasgow= 6) participated in this study seven months after the trauma. The patient was 99 days hospitalized, with 72 days in the ICU in induced coma and presented an image examination showing diffuse axonal lesion and subdural hematoma on the left.

The patient was submitted to: clinical history; Inspection of external auditory meatus; tonal and vocal audiometry: immittance testing; Behavioral evaluation of auditory processing and Short (BEAP) and Long latency (P300) auditory evoked potentials previous to, immediately after and six months after the acoustically controlled auditory training (ACAT).

Auditory evoked potentials were registered using a Traveler Express device from the brand Biologic Evoked Potential and the registers were recorded in an acoustically treated and electrically protected room. The data gathering was initiated by the P300 and afterwards BEAP was performed, since the P300 is influenced by the state of alertness and attention to the acoustic stimulus, whereas the BEAP does not suffer this type of influence.

To obtain the P300, binaural tone burst auditory stimuli were used with frequencies of 1,000 Hz for the frequent stimulus and 2,000 Hz for the rare stimulus, with intensity of 80 dBHL for both. There were 300 stimuli, 240 for the frequent and 60 for the rare, in a ratio of 80% for the frequent and 20% for the rare. The polarity used was alternated, the presentation speed of the stimuli occurred at regular intervals of one per second and the filter used was from 0.5 to 20 Hz. The registration window was of 750 ms. At each scan, two waves were recorded, one for frequent stimulus and one for rare. At the end, the waves were subtracted to obtain P300.

In the Brainstem Auditory Response (BAER), click stimuli presented monaurally at 80dBNA were used, with rarefied polarity and presentation speed of 19.1 clicks / second. Registration window was set from 0 to 10.24 milliseconds and the low-pass and high-pass filters were 3,000Hz and 100Hz respectively. To analyze the reproducibility of the tracing, a total of 2,000 stimuli were presented twice. The absolute latencies of waves I, III, and V and the interpeak intervals I-III, III-V and I-V were marked and recorded.

Behavioral auditory processing evaluation included the simplified evaluation of the auditory processing performed in free field (sound localization test and verbal and nonverbal sequential memory tests) and by six tests performed in acoustic booth using verbal and nonverbal stimuli recorded in compact discs presented by means of a two-channel audiometer, namely: speech in noise test (SPIN), staggered spondaic word test(SSW), duration pattern test (DPT), dichotic consonant-vowel test - free recall (DCVT), synthetic sentence identification with ipsilateral competitive message (SSI-ICM) and random gap detection test (RGDT)

ACAT program was organized in eight sessions, each of them lasting 45 minutes, performed twice a week, following Ziliotto, Pereira proposal (in press) [8]. In this program, the sessions, as well as the activities in each session, were organized in increasing order of complexity with the objective of challenging the auditory system. For this, the signal-to-noise ratio was varied from positive (more favorable) to negative (less favorable).

The program involved the training of temporal ordering skills (frequency pattern and duration of sounds), auditory closure (sentences, words and figures) and figure-to-ground for sentences, words and CVC words and for non-verbal tests (environmental sounds) in monotic and dichotic tasks. The patient was asked to point phrases, digits, repeat sounds or imitate the presented sound patterns.

Right and left ears were trained separately. Thus, in a training session, aiming at training the right ear, the sounds presented on the left should be ignored by the patient and vice versa. Regarding the level of intensity, the ear under training had its intensity fixed, while the presentation intensity in the contralateral ear was progressively increased, causing a change in the signal-to-noise ratio, from positive to negative, that is, from the easiest to the most difficult condition, using the DIID paradigm(dichotic interaural intensity interval). It is worth emphasizing that, in general, and whenever possible, the tests used in the training were different from those used in evaluation and re-evaluation in order to eliminate the learning effect.

In each training session, an accuracy score of about 70% was required to move to the next stage, in order to maintain motivation and avoid patient frustration[9].

The results of electrophysiological and behavioral evaluations of central auditory processing were classified as normal and altered. The results were considered normal if they were within the following standards:

I - BAEP: Absolute latencies of waves I, III, and V and interpeaks I - III, III - V and I - V per ear were recorded and documented. Normality criteria used to evaluate auditory pathway integrity (absolute and interpeak latencies) were the ones suggested by the equipment manufacturer. The alterations were classified as: low brainstem lesion, high brainstem lesion or diffuse brainstem lesion.

II - P300: For the analysis of this potential, the latency of the P3 wave was considered. Normal values used were those proposed by McPherson (1996) [10].

III - Central Auditory Processing: Normality criteria used for behavioral evaluation of auditory processing were described by Pereira (2004)[11].

RESULTS

In clinical history, the patient reported the following speech-language complaints: difficulty in locating sounds, agitation, slowed speech, difficulty in reading and writing, attention and memory deficits.

Regarding behavioral and electrophysiological evaluations of auditory processing, the results are presented in the tables below. They are divided into three periods, namely: 1- Before ACAT 2- Immediately after ACAT; 3- Six months after ACAT.

Table 1 shows the results of auditory processing behavioral tests that were measured by percentage. The other tests as well as the altered gnosic processes considering three moments of the evaluation will be presented in separate tables (Tables 2, 3 and 4). Results of electrophysiological evaluation will be presented in Table 5 and in Figures 1, 2 and 3.

Table 1. Results of auditory processing behavioral tests obtained in the three evaluations

Period.	SL	VSM		NVSM		SPIN		DCVT		SSI-MCC (-40)		SSI-MCI (0)		SSI-MCI (-10)		SSI-MCI (-15)		DPT
		3 sounds	4 sounds	3 sounds	4 sounds	RE	LE	OD	OE	RE	LE	RE	LE	RE	LE	RE	LE	
1	80%		100%	100%	33,30%	96%	96%	100%	90%	100%	100%	100%	100%	80%	90%			73%
2	80%		100%	100%	66,60%	96%	96%	100%	92,50%	100%	100%	100%	100%	90%	90%	100%	100%	90%
3	100%		100%		100%	96%	96%	100%	95%	100%	100%	100%	100%	100%	100%	100%	100%	93,30%

Time; RE: right ear; LE: left ear; SL: sound localization test; VSM: verbal sequential memory test; NVSM: nonverbal sounds sequential memory test; SPIN: speech in noise test; SSI (MCI/MCC): synthetic sentence identification with ipsilateral /contralateral competitive ; DCTV dichotic consonant-vowel test - free recall; DPT: duration pattern test

Table 2. Results of the dichotic consonant-vowel test - free recall; and RGDT obtained in the three evaluations

Time	DCVT – Free attention			RGDT
	RE	LE	Mistakes	
1	9 hits	7 hits	8	12,5ms
2	13 hits	5 hits	6	8,75ms
3	14 hits	1 hits	9	8,75ms

RE: right ear; LE: left ear; DCVT: dichotic consonant-vowel test - free recall; RGDT random gap detection test.

Table 3. SSW qualitative assessment data in the three evaluations

Time.	SSW - Analisy Qualitative					
	H/L Auditory effect	L/H Auditory effect	H/L Order effect	L/H Order effect	Inversions	TypeA
1			X			
2				X		
3						

H/L: high/low; L/H low/High

Table 4. Altered gnosic processes in the three evaluations

ALTERED GNOSIC PROCESSES				
Time	Decoding	Coding	Organization	Non Verbal
1	X	X	X	X
2	X			
3	X			

Table 5. Results of electrophysiological evaluation the auditory processing obtained in the three evaluations

Time.	BEAP																			P300			
	RE Latency						RE AMP.			LE Latency						LE AMP.			latency		amplitude	
	I	III	V	I-III	III-V	I-V	I	III	V	I	III	V	I-III	III-V	I-V	I	III	V	A2	A4	A2	A4
1	1.68	3.86	5.63	2.18	1.77	3.95	0.21	0.15	0.08	1.74	3.92	5.57	2.18	1.65	3.84	0.14	0,03	0.03	279.20	294.20	6.61	9.06
2	1.62	3.86	5.45	2.24	1.59	3.84	0.21	0.13	0.18	1.56	3.86	5.34	2.30	1.47	3.78	0.21	0.24	0.20	316.20	320.20	10.51	11.10
3	1.68	3.86	5.45	2.18	1.59	3.78	0.08	0.25	0.25	1.56	3.80	5.39	2.24	1.59	3.84	0.10	0.26	0.14	304.20	305.20	13.04	13.09

RE: right ear; LE: left ear; AMP.: amplitude; BEAP: Behavioral evaluation of auditory processing

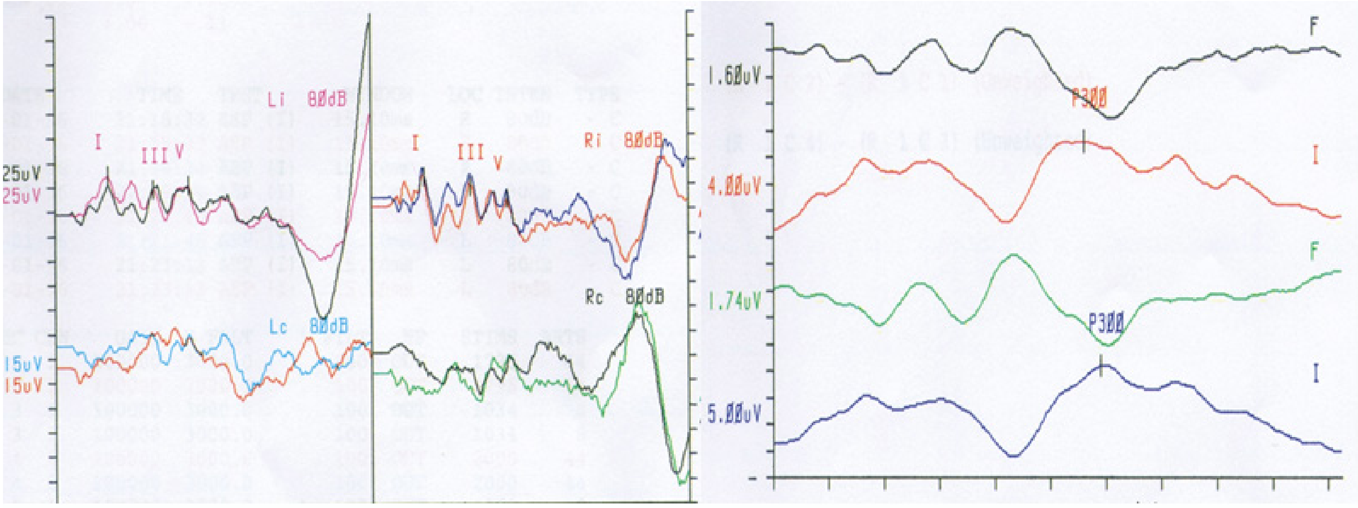

Figure 1. BEAP and P300 in evaluation 1

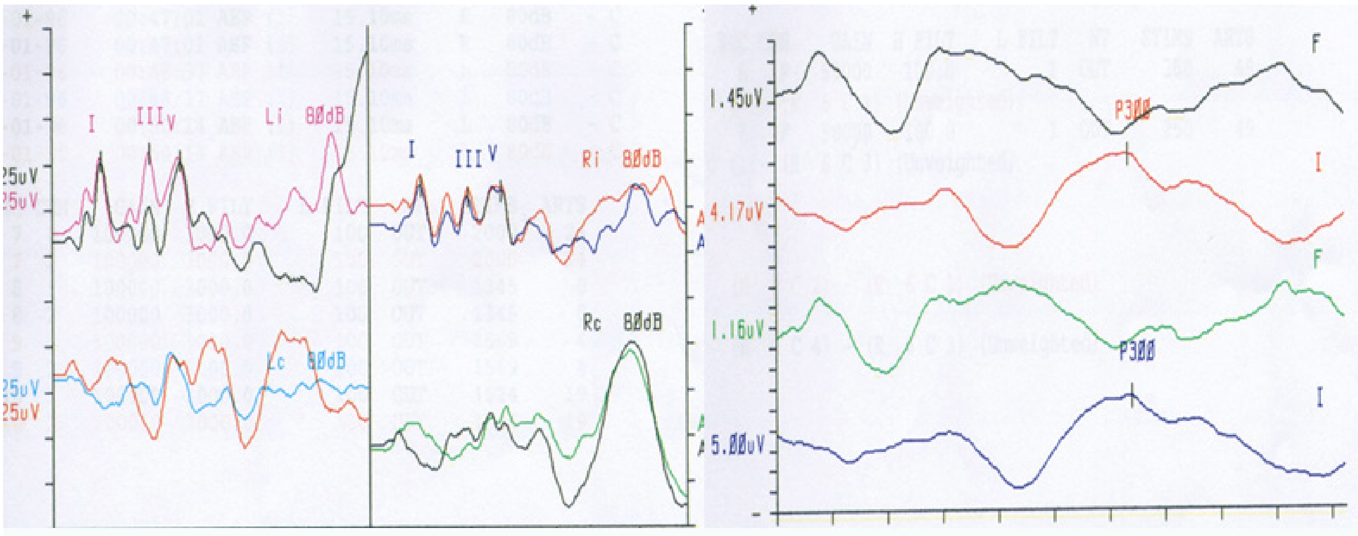

Figure 2. BEAP and P300 in evaluation 2

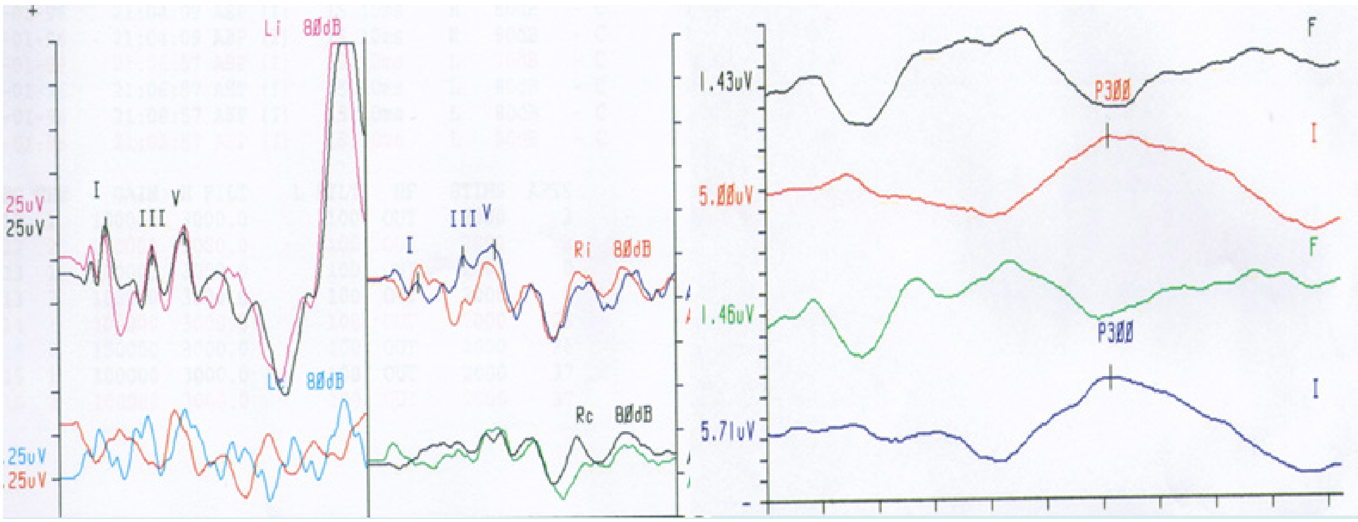

Figure 3. BEAP and P300 in evaluation 3

It was observed that immediately after the acoustically controlled auditory training (Time 2), the patient presented an improvement in the behavioral auditory processing evaluation, presenting an alteration only in the dichotic consonant-vowel test - free recall, despite having presented improvement in the right ear advantage in this test compared to the initial evaluation (evaluation 1), that is, the patient presented a significant improvement in the behavioral auditory processing evaluation after ACAT (Tables 1, 2 and 3). In addition, as for the gnosic processes, in the initial evaluation (evaluation 1) the individual presented alteration in all the gnosic processes and immediately after the training (Evaluation 2), only the decoding decifit remained, revealing significant improvement (Table 4).

Concerning electrophysiological evaluation, improvement in wave morphology, amplitude and latency of the BEAP, which previously showed a lower brainstem dysfunction in the left ear. An improvement in the amplitude of the P3 component was observed in the Evaluation 2, although no changes related to latency of this component was observed (Table 5 and Charts 1 and 2).

It was observed that six months after ACAT, the performance of the individual in the behavioral and electrophysiological evaluation remained unchanged or improved, as in Duration Pattern Test, in the SSW (Qualitative Analysis), and in the amplitude of the P300 component (Tables 1, 2 , 3, 4 and 5 and Chart 3).

DISCUSSION

It is important to emphasize that there is a limited number of studies in the literature that directly addresses to the theme of this case, especially in individuals with damaged brains, making necessary the correlation with other populations.

After ACAT, it could be observed an improvement in the behavioral auditory processing evaluation, with an improvement or even adjustment in auditory abilities (Tables 1 to 4), which are commonly altered in individuals after TBI, as shown in some studies that performed auditory processing evaluation In this population[12-14].

The data found in the DCVT Test – Free Recall (Tables 2) demonstrated that the individual presented a greater number of right ear hits in the two moments after ACAT, that is, he showed an right ear advantage that he did not initially demonstrated, which is often associated to left hemispheric dominance for linguistic sounds in right-handed individuals[15].

In the RGDT test (Table 2), the individual's performance changed from abnormal to normal after ACAT, showing an adequacy of the temporal resolution auditory ability, which is related to phonological aspects and auditory discrimination[16].

Regarding the qualitative analysis of the SSW test (Table 3), it was observed that initially (Evaluation 1) the patient had the high / low order effect, which is related to a difficulty in auditory memory. In the second moment of the evaluation, the patient presented a low/ high order effect, and in the last evaluation (Evaluation 3), there were no errors tendencies. Therefore, it was observed that the individual presented an improvement in the qualitative analysis of SSW, and this finding is relevant, since it is an individual who had suffered TBI. It is known that individuals who suffer TBI may have temporary or permanent deficiencies and disabilities, such as visual, motor, linguistic, cognitive and/or behavioral. The most frequent are memory, attention and organization alterations[17]. Thus, in observing the data, it can be stated that ACAT has helped the individual to improve a common difficulty found in this population, which can benefit the quality of life, since with better memory capacity it is possible that the communicative exchanges to be more efficient.

As for the impaired gnostic processes (Table 4), a significant improvement was observed after ACAT, and in the initial evaluation the individual presented alterations in all the gnostic processes and after the auditory training, only the decoding alteration remained. As previously mentioned, with these data, we observed an improvement in two cognitive alterations commonly found in post-TBI subjects: organization and memory (coding/gradual memory loss), helping to improve the quality of life of the patient. It is worth mentioning that the decoding alteration found after ACAT may have elapsed from the limitation imposed by the lesion presented by the patient. In addition, the purpose of auditory training is not to make the tests normal from a quantitative point of view, but to make individuals more adapted and able to establish more efficient communicative exchanges in their daily lives.

According to one study[18], an intense and increasing order of complexity ACAT tends to maximize cortical plasticity and, consequently, results in learning. This was precisely the proposal of the auditory training described in this individual, and, thus, these behavioral results demonstrated that the ACAT favored the neuronal plasticity, reflecting in behavioral change. Several authors have shown an improvement in auditory abilities after ACAT, due to the alteration of the neural substrate, reaffirming the data of this research, suggesting the ACAT as a rehabilitation tool for central auditory deficits[9,19,20].

Regarding the auditory electrophysiological evaluation (Table 5), the individual presented, after the ACAT, an improvement in the wave morphology, amplitude and latency of the BAEP, which previously presented a left brainstem change and an improvement in the amplitude of the Component P3. After six months of ACAT (evaluation 3), it was observed that BAEP remained unchanged and there was an increase in the amplitude of the P3 component, although no improvement was observed in the latency of this wave after auditory training. These findings demonstrated an objective measure of the neuronal plasticity caused by ACAT, since according to authors[21], auditory training is a set of tasks designed to activate the auditory and associated systems, so that there are beneficial changes in auditory behavior and central auditory nervous system. The changes observed in the auditory evoked potentials after auditory training, related to latency and/or amplitude, are due to the excitation of a large number of neurons and greater neuronal synchrony[22].

Although different authors[23,24] recommend the use of auditory evoked potentials to monitor the neurophysiological changes brought about by auditory training, the type of potential most used for this purpose is the long-latency auditory evoked potential, since neuronal plasticity is different throughout the auditory pathway, being greater in the cortical regions[25,26]. Thus, there are few studies that used BAEP to monitor changes after auditory training, and the two studies that used BAEP with speech stimulus did not report significant changes after training[25,26], whereas the only study carried out with click stimulus[27] presented an improvement in BAEP after auditory training in children with auditory processing disorders. However, considering the findings of the present study, BAEP proved to be an effective method for measuring the neuronal plasticity caused by stimulation and should be included in the post-intervention monitoring studies.

Previous studies using long-latency auditory evoked potentials to assess neurophysiological changes after auditory training indicated an improvement in amplitude, latency and/or wave morphology after the auditory stimulation period, and there was no consensus on which measurement, amplitude or latency would be the most sensitive to detect neuronal plasticity[20,23-26]. In this case, the extent of the change was the amplitude of the wave.

It was observed that six months after the ACAT, the performance of the individual in the behavioral and electrophysiological evaluation remained stable or even improved, such as in the Duration Pattern Test, the SSW (Qualitative Analysis), and the amplitude of the P3 component (Tables 1 To 5 and charts 1 to 3), demonstrating that acoustically controlled auditory training provided an alteration of the neuronal substrate, that is, triggering the effect of neuronal plasticity, remaining stable over time, as demonstrated by the behavioral and electrophysiological evaluations.

Studies shows that neural changes often precede behavioral ones[28,29] suggesting that a longer follow-up (in terms of time) can bring about even greater improvement in auditory abilities. It is known that when trained individuals expose themselves to activities with a hearing demand, such as communicating in a noisy environment, the environment itself will keep the hearing abilities improved and still allow them to continue to be improved.

Authors[21] reported that if a rehabilitation generates neuronal changes, it can be said that the intervention strategy was successful. Thus, it is possible to affirm that, in this case, the ACAT was effective in rehabilitating the central auditory alterations found in this patient who suffered TBI, supporting a study[30] that showed improvement in the symptoms, the behavioral and electrophysiological evaluations of the AP, post auditory training, in a patient who suffered a mild TBI.

It is known that neuronal plasticity in injured individuals occurs differently from those without brain injury. However, this case showed that ACAT was efficient in promoting neuronal plasticity through stimulation in individuals after TBI, adjusting auditory abilities and being able to partially compensate for cognitive, metacognitive and metalinguistic deficits, as mentioned by authors[2].

CONCLUSION

Acoustically controlled auditory training proved to be effective in developing and refining different auditory skills as demonstrated in behavioral and electrophysiological assessment in an individual following severe brain injury and a stability in auditory skills were observed six months after auditory training.

REFERENCES

1. Braga FM, Ferraz FAP. Traumatismo crânio-encefálico. In: Prado FC, Ramos J, Valle JR, organizadores. Atualização terapêutica: manual prático de diagnóstico e tratamento. 17ª ed. São Paulo: Artes Médicas; 1995. p. 728-30.
2. Musiek FE, Chermak G. Testing and treating (C) APD in head injury patients. Hear J. 2008;61(6):36-8.
3. Jeger S & Jeger J.Alterações auditivas. Um Manual para Avaliação Clínica. 1a. ed. (Trat. Auditory Disorders Little Brown and Company), Rio de Janeiro, Livraria Atheneu Editora, 1989.
4. Bergemalm PO, Lyxell B. Appearances are deceptive:Long-term cognitive and central auditory sequelae from closed head injury. IJA. 2005;44(1):39-49.
5. Lendrem W, Lincoln NB. Spontaneous recovery of language in patients with aphasia between 4 and 34 weeks after stroke. J Neurol Neurosurg Psychiatry. 1985;48(8):743-8.
6. Nudo J. Neural bases of recovery after brain injury. J Commun Disord. 2011;44(5):515-20.
7. Musiek FE, Berge BE. How electrophysiologic tests of central auditory processing influence management. In Bess F, (editor). Children with hearing impairment. Nashville, Vanderbilt: Bill Wilkerson Center Press, 1998. p.145-62.
8. Ziliotto ZN, Pereira LD. Estimulação auditiva em cabina acústica: relato de caso. In Pereira, LD, Azevedo MF, Machado LP, Ziliotto KN. Processamento auditivo: terapia fonoaudiológica. Uma abordagem de reabilitação. São Paulo: Lovise [no prelo].
9. Musiek FE, Schochat E. Auditory training and central auditory processing disorders: a case study. Semin Hear. 1998;19(4):357-65.
10. McPherson DL. Late potencials of the auditory system (evoked potencials). Singular Press. Cidade. 1996.
11. Pereira LD. Avaliação do processamento auditivo central. In: Lopes-Filho O. (organizador). Tratado de Fonoaudiologia, 2ª edição, São Paulo: Tecmedd; 2004. p.111-30.
12. Murphy CFB, Fillippini R, Palma D, Zalcman TE, Lima JP, Schochat E. Auditory training and cognitive functioning in adult with traumatic brain injury. Clinics. 2011;66(4):713-5.
13. Turgeon C, Champoux F, Lepore F, Leclerc S, Ellemberg D. Auditory processing after sport-related concussions. Ear Hear. 2011;32(5):667-70.
14. Santos RBF, Marangoni AT, Andrade AN, Vieira MM, Ortiz KZ, Gil D. Avaliação comportamental do processamento auditivo em indivíduos pós traumatismo cranioencefálico: estudo piloto. Rev. CEFAC. 2013;15(5):1156-62.
15. Bradshaw JL, Nettleton NC. Human cerebral asymmetry. New Jersey: Prentice Hal; 1983.
16. Keith RW. RGDT – Random gap detection test. St. Louis: Auditec; 2000.
17. Leathem J, Heath E, Woolley C. Relatives' perceptions of role change, social support and stress after traumatic brain injury. Brain Inj. 1996;10(1):27-38.
18. Merzenich MM, Jenkins WM, Johnston P, Schreiner C, Miller SL, Tallal P. Temporal processing deficits of language-learning impaired children ameliorated by training. Science. 1996;271(5245)77-81.
19. Zalcman TE, Schochat E. A eficácia do treinamento auditivo formal em indivíduos com transtorno de processamento auditivo. Rev Soc Bras Fonoaudiol. 2007;12(4):310-4.
20. Gil D, Iorio MC. Formal auditory training in adult hearing aid users. Clinics. 2010;65(2)165-74.
21. Musiek FE, Berge BE. A neuroscience view of auditory training/stimulation and central auditory processing disorders. In Masters MG, Stecker NA, Katz J. Central auditory processing disorders – mostly management. Boston: Allyn and Bacon; 1998. p. 15-32.
22. Cone-Wesson B, Wunderlich J. Auditory evoked potentials from the cortex: audiology applications. Current Opinion on Otolaryngology and Head and Neck Surgery. 2003; 11(5):372-7.
23. Musiek FE, Shinn J, Hare C. Plasticity, auditory training and auditory processing disorders. Seminars in Hearing. 2002;23(4):264-75.
24. Tremblay KL, Kraus N. Auditory training induces asymmetrical changes in cortical neural activity. J Speech Lang Hear Res. 2002;45(3):564-72.
25. Hayes EA, Warrier CM, Nicol TG, Zecker SG, Kraus N. Neural plasticity following auditory training with learning problems. Clin Neurophysiol. 2003;114(4):673-84.
26. Russo NM, Nicol TG, Zecker SG, Ilayes EA, Kraus N. Auditory training improves neural timing in the human brainstem. Behav Brain Res. 2005;156(1):95-103.

27. Vieira HS, Reis ACMB. Avaliação da efetividade do treinamento auditivo em grupo com crianças com alteração de processamento auditivo. Trabalho de conclusão de curso –FMRP/USP. 2009.
28. Tremblay K, Kraus N, McGee T. The time course of auditory perceptual learning: neurophysiological changes during speech-sound training. Neuroreport. 1998;9(16):3557-60.
29. Kraus N. Speech-sound perceptual learning. Hear J. 1999;52(11):64-6.
30. Musiek FE, Baran JA, Shinn J. Assessment and remediation of an auditory processing disorder associated with head trauma. J Am Acad Audiol. 2004;15(2):117-32.