Behavioral assessment of auditory processing before and after formal auditory training in traumatic brain injury patients

Avaliação comportamental do processamento auditivo pré e pós treinamento auditivo formal em indivíduos após traumatismo cranioencefálico

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ABSTRACT

Purpose: To investigate the effects of formal auditory training on individuals with traumatic brain injury using behavioral tests. **Methods:** Nine normal hearing individuals who had severe traumatic brain injury underwent behavioral evaluation of auditory processing pre and post formal auditory training. Eight sessions took place in an attempt to train the auditory skills of temporal ordering, auditory closure and figure-ground. **Results:** All individuals improved in all tests after the training, improving the auditory skills of temporal ordering and figure-ground of verbal sounds. In terms of the altered gnosis processes, a significant improvement was found for encoding (gradual loss of memory and sensory integration) and organization. **Conclusion:** After formal auditory training, individuals with severe traumatic brain injury exhibited adequacy in the auditory skills of figure-ground, temporal ordering and resolution.

Keywords: Hearing; Auditory diseases Central; Neuronal plasticity; Rehabilitation; Brain injuries

RESUMO

Objetivo: Verificar os efeitos do treinamento auditivo formal em indivíduos após traumatismo cranioencefálico, utilizando testes comportamentais. **Métodos:** Nove indivíduos audiologicamente normais, que haviam sofrido traumatismo cranioencefálico grave, com lesão axional difusa, com ou sem lesão focal associada, foram submetidos à avaliação comportamental do processamento auditivo pré e pós treinamento auditivo formal em cabina acústica, organizado em oito sessões, visando o treinamento das habilidades auditivas de ordenação temporal, fechamento auditivo e figura-fundo. **Resultados:** Observou-se melhora no desempenho em todos os testes, após o treinamento, refletindo em uma melhora das habilidades auditivas de ordenação temporal e figura-fundo, para sons verbais. Quanto aos processos gnósicos alterados, observou-se melhora significativa para codificação (perda gradual de memória e integração sensorial) e organização. **Conclusão:** Indivíduos com lesão axional difusa, após sofrerem traumatismo cranioencefálico grave, apresentaram adequação das habilidades auditivas de figura-fundo, ordenação e resolução temporal, evidenciadas na avaliação comportamental do processamento auditivo, pós treinamento auditivo formal.

Descritores: Audição; Doenças auditivas centrais; Plasticidade neuronal; Reabilitação; Traumatismos encefálicos

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INTRODUCTION

Traumatic brain injury (TBI) is a result of physical assaults on the skull, and the injuries caused by the impact and movement acceleration/deceleration of the brain within the skull, which may be primary and/or secondary[1].

The primary lesions that occur during the accident, are extradural and the subdural hematoma, diffuse axonal injuries and bruises.

The deformation of the brain, because of extreme acceleration and deceleration, compromises nerve fibers, which may affect the neural substrate responsible for hearing. This can cause central auditory deficits, mainly diffuses axonal injuries because it involves several areas, such as auditory cortical and subcortical[2].

As a frequency of lesions of the brain stem and cortex are found in patients with TBI, behavioral evaluation of auditory processing (AP) becomes important to verify the functioning of the central auditory pathway. Many individuals who suffer TBI have auditory processing disorder (APD), which can only be identified with special tests[2,3]. Some studies apply the behavioral evaluation of auditory processing in individuals who have suffered TBI and showed changes in this population[4-6].

Since changes in the auditory pathway that can be found in individuals after TBI and can compromise the communication, it is necessary to propose a rehabilitation program for these patients in order to improve their quality of life.

Spontaneous recovery after brain injury, specifically after TBI, occurs in the first three months, particularly in the first month. After this period a damaged brain may change and readjust by means of neuronal plasticity induced by stimulation with the size, location and severity of lesions limiting factors[7,8].

Formal auditory training (FAT) is a therapeutic method that aims to auditory stimulation, to maximize the effects of plasticity of the central nervous system that leads to positive behavioral changes[9].

Studies in different populations showed improvement in AP, evidenced in the hearing skills after auditory training, suggesting it as a tool to rehabilitate the central auditory disorders by causing changes in the neural substrate[10-13]. These findings also reported in a study that the authors observed an improvement in symptoms, the behavioral and electrophysiological AP after auditory training in a patient who suffered mild TBI[14].

The aim of this study was to verify the effects of a formal program of auditory training in patients after traumatic brain injury using behavioral tests.

METHODS

This research performed in the auditory processing laboratory, which is part of the Discipline Hearing Disorders, in Universidade Federal de São Paulo (UNIFESP), after approval by the institution's Research Ethics Committee (nº. 0389/10). All subjects read and signed an informed consent before study participation.

The inclusion criteria in this study were individuals who suffered severe closed TBI (Glasgow Scale of three to eight at hospital admission); stay only in induced coma; diffuse axonal injury, with or without associated focal lesion; time between injury and participation the study of three to 24 months; age between 18 and 50 years; both genders; right hand preference; complete high school and hearing thresholds within the normal range, between 250 and 8000 Hz. Individuals should not exhibit obvious behavioral changes and should be able to perform the study procedures and should be forwarded by the Clinic of Neurological Disorders Acquired or of Neurosurgery, UNIFESP.

Adults selected between 18 and 50 years in order to avoid the influence of age on outcomes of behavioral evaluations of AP, as these tests influenced by the aging and degeneration of the central auditory pathway process. Furthermore, we chose to select individuals with the right hand preference, since manual preference influences the interpretation of the behavioral evaluation of AP. The criterion of minimum education - completed high school - aimed at individuals who had similar time schooling. Thus, the variable does not interfere with its performance individuals during the rehabilitation process (FAT). Regarding the type of injury, was selected to diffuse axonal injury because it compromises the nerve fibers, occurring distension and rupture of axons in the brain, involving several areas, such as cortical and subcortical auditory[2]. Regarding the time of injury, were selected individuals who had suffered TBI between three months and two years in order to avoid the influence of spontaneous recovery after brain injury.

The study included nine subjects were male, between 20 and 37 years (mean age, 27 years) who had suffered severe TBI (Glasgow scale admission mean: 5.7). There are approximately ten months and an average hospital stay of 50.6 days, and 24.7 days in an induced coma. Nine individuals, six had completed high school and three incomplete higher education.

All participants had speech complaints, such as loss of memory, attention, and difficulty understanding in noisy environments and speech production and/or reading and writing. Regarding the type of injury, all had diffuse axonal injury, and two subjects had no associated focal lesion; three had subdural hematoma; one extradural hematoma; one temporal contusion; one temporal, and frontal contusion and one subdural hematoma and associated temporal contusion.

All subjects underwent the following procedures:

1. Collection of clinical history to obtain data regarding the hearing and TBI;
2. Visual inspection of the external auditory canal, to check for possible obstructions that could interfere with the application of other procedures;
3. Behavioral evaluation and revaluation of AP pre and post FAT had the following tests[15-19]: sound localization (SL);

Memory for verbal sounds (MVS) and nonverbal (MNVS); speech with white noise (SWN); alternate disyllabic dichotic test (SSW); a synthetic sentence identification with ipsilateral competing message (SSI-MCI) and contralateral (SSI-MCC); the duration pattern test with pure tone (DP); dichotic consonant-vowel (DCV), and randomized auditory fusion test (RGDT).

4. FAT is organized into eight sessions lasting 45 minutes each, twice a week, based on previous studies have proposed[20,21].

The auditory training sessions organized in ascending order of complexity as well as the activities in each session. This can promote intense stimulation and activities that challenge the auditory system.

The program involves the training of skills temporal ordering (standard frequency and duration of sounds[17,18,22,23]), auditory closure (available on CD lists of sentences in Portuguese[24] and Speech in Noise test with Figures), and figure-ground for verbal sounds (PSI test , the dichotic listening test and test DCV) and nonverbal (nonverbal dichotic Test) in monotic tasks and dichotic listening. Patients asked to point out sentences, digits, repeating sounds verbally or imitate the sound patterns that were presented. The right and left ears were trained separately. Thus, in a training session, which aimed to train the right ear, the sounds presented to the left should be ignored by the patient and vice versa. Regarding the level of intensity, ear training had under its intensity fixed, while the intensity of the presentation in the contralateral ear was progressively increased, causing change in signal to noise ratio of positive to negative, from easiest to most difficult. Most of the time, the tests used in training were different from those used in the evaluation and revaluation in order to eliminate the effect of learning.

Each training session, we tried to maintain a hit rate around 70% to move to the next step, maintain motivation and avoid the frustration of the patient[10].

The collected data were analyzed statistically by using the Wilcoxon test to compare the results of behavioral evaluations AP pre and post FAT. As no significant difference was found between the ears, the analysis was performed considering both ears. Thus, the sample size was doubled and remained intrinsic variability of the data, making the results greatly in reliability. The statistically significant results were highlighted with the asterisk symbol (*) and results with a trend towards significance were highlighted with the pound symbol (#). Confidence intervals were constructed with 95% statistical confidence was established and a significance level of 0.05 (5%).

RESULTS

The results of the performance of individuals on tests of behavioral evaluation pre and post the AP and FAT could be measured in percentages. Have the dichotic consonant-vowel and RGDT tests had their results measured respectively in number of hits/errors and answers in milliseconds. It was found significant improvement after FAT tests for MNVS - Four Sounds (MNVS), SSW, SSI-MCI and PD, while the FWN test showed trend towards statistical difference (Table 1).

Regarding DCV test - Free Attention, we observed that after FAT, subjects had more responses that are correct and fewer errors, tending toward statistical significance (Tables 2 and 3).

Qualitative analysis of the SSW test, there was significantly lower incidence trend of the effect of errors of high/low order type after FAT (Table 4).

Regarding the degree of alteration of the AP from the SSW test, no differences were found; most subjects had mild change or no change in the degree after FAT (Figure 1).

RGDT results, it was observed that the mean interval of frequencies in milliseconds, required for individuals to realize the presence of two sounds, was lower in the evaluation after FAT compared with the first evaluation, no statistical significance (Table 5).

Regarding harmed gnosis processes, there was significantly decreased after FAT, in the gnosis encoding processes (gradual loss of memory and sensory integration) and organization (Figure 2).

DISCUSSION

There are few studies in the literature that directly studying individuals with damaged brains, so the correlation with other populations is needed.

The focal lesions associated with diffuse axonal injury were mostly subdural hematomas and lobes most affected were the frontal and temporal, because of the biomechanical strength of the trauma. The subdural hematomas generated by the acceleration and deceleration mechanism of the head, as well as diffuse axonal injuries, most commonly a combination of these two types of injury[25].

The data found in the behavioral evaluation of AP (Table 1) are important because they show that the FAT helped individuals after TBI, improve and often fit hearing skills that are commonly altered in this population, as shown in some studies that AP evaluation conducted in individuals after TBI[4-6].

The data found in DCV test - Free Attention (Tables 2 and 3), showed that the participants had more correct responses and fewer errors , tending to the statistical difference , indicate that this test passed changed to normal after FAT, indicating suitability auditory skill of figure-ground to syllables. The fact that they have more hits in the right ear, with no statistical significance, which is often associated with, left hemispheric dominance for language sounds, it was expected for individuals with right hand preference. Furthermore, although not the objective of the DCV test, excessive errors encountered because of the difficulty of auditory discrimination, since the test comprises syllables that differ only regarding the line of sound. Thus, configuration errors that more hits after FAT

Table 1. Performance of individuals in the behavioral evaluation of auditory processing pre and post formal auditory training

Behavioral			Mean (%)	Median (%)	Standard deviation (%)	Q1 (%)	Q3 (%)	n	CI (%)	p-value
SL		Pre	86.7	80.0	10.0	80.0	100.0	9	6.5	0.157
		Post	91.1	100.0	10.5	80.0	100.0	9	6.9	
SVM	3 sounds	Pre	77.8	100.0	37.3	66.6	100.0	9	24.4	0.109
		Post	100.0	100.0	0.0	100.0	100.0	9	- x -	
	4 sounds	Pre	70.4	100.0	38.9	33.3	100.0	9	25.4	0.176
		Post	88.9	100.0	16.7	66.6	100.0	9	10.9	
SMNV	3 sounds	Pre	88.9	100.0	23.6	100.0	100.0	9	15.4	0.180
		Post	100.0	100.0	0.0	100.0	100.0	9	- x -	
	4 sounds	Pre	55.5	66.6	33.3	33.3	66.6	9	21.8	0.042*
		Post	85.2	100.0	17.6	66.6	100.0	9	11.5	
SWN		Pre	86.0	88.0	9.7	81.0	92.0	18	4.5	0.086#
		Post	88.7	88.0	7.3	84.0	95.0	18	3.4	
SSW		Pre	84.0	86.3	11.4	75.0	93.8	18	5.3	0.001*
		Post	93.3	95.0	6.4	90.0	97.5	18	3.0	
SSI-MCC (-40)		Pre	97.2	100.0	7.5	100.0	100.0	18	3.5	0.102
		Post	100.0	100.0	0.0	100.0	100.0	18	- x -	
SSI-MCI (0)		Pre	89.4	100.0	18.6	90.0	100.0	18	8.6	0.027*
		Post	100.0	100.0	0.0	100.0	100.0	18	- x -	
SSI-MCI (-10)		Pre	71.7	75.0	23.1	52.5	90.0	18	10.7	0.004*
		Post	87.2	90.0	9.6	80.0	90.0	18	4.4	
DP		Pre	80.7	86.6	16.2	73.0	90.0	9	10.6	0.035*
		Post	89.2	90.0	10.0	83.3	96.6	9	6.5	

* Significant values (p<0.05) - Wilcoxon test

\# Trend towards statistical significance

Note: Q1 = first quartile, Q3 = third quartile, CI = confidence interval; SL = sound localization; SVM = sequential verbal memory; SMNV = sequential memory of non-verbal sounds; SWN = test speech with white noise; SSW = dichotic test alternate dissyllable; SSI (MCI/MCC) = synthetic sentence identification (ICM/contralateral competing message), DP = duration pattern

Table 2. Number of hit and errors in consonant vowel dichotic test pre and post formal auditory training

DCV - Free Attention	Hits		Errors	
	Pre	Post	Pre	Post
Mean	8.83	9.89	6.22	4.22
Median	8.0	9.5	6.0	5.0
Standard Deviation	4.00	5.10	2.77	1.56
Q1	6.0	5.3	4.0	3.0
Q3	11.5	14.5	8.0	5.0
n	18	18	9	9
CI	1.85	2.35	1.81	1.02
p-value	0.201		0.088*	

* Significant values (p<0.05) - Wilcoxon test

Note: DCV = dichotic consonant-vowel test, Q1 = first quartile, Q3 = third quartile, CI = confidence interval

Table 3. Number of hits on the right and left ear in dichotic consonant vowel test pre and post formal auditory training

DCV – Hits	RE		LE	
	Pre	Post	Pre	Post
Mean	11.56	13.67	6.11	6.11
Median	12.0	15.0	6.0	5.0
Standard deviation	3.64	3.67	2.03	3.10
Q1	9.0	12.0	5.0	4.0
Q3	14.0	15.0	7.0	9.0
n	9	9	9	9
CI	2.38	2.40	1.32	2.03
p-value	0.122		1.000	

Wilcoxon Test (p<0.05)

Note: DCV = dichotic consonant-vowel test, Q1 = first quartile, Q3 = third quartile, CI = confidence interval

demonstrated that hearing rehabilitation probably improved auditory discrimination of these patients[16].

The qualitative analysis of the SSW test (Table 4), which noted that individuals had fewer errors in the evaluation of trends after FAT when compared with the initial evaluation and the tendency to errors of the effect of high/low order type was significant. The effect of high/low order associated with difficulty in auditory memory. This fact is relevant, especially in individuals after TBI. Individuals suffering from TBI may have disabilities, temporary or permanent, whether visual, motor,

and language, cognitive and/or behavioral. The most frequent are the changes of memory, attention and organization[26]. Thus, it can be stated that the FAT helped individuals improve a difficulty commonly found in this population, which may benefit the quality of life, since with better memory capacity is possible that the communicative exchanges are more efficient. Moreover, it was observed that the only trend that persisted errors in assessing post FAT was the effect of low/high order, showing the improvement in the qualitative analysis of SSW.

Regarding the data on the degree of change from the SSW (Figure 1), which showed improvement after FAT, since most subjects had mild change, or no change in the degree, we note that this grade rating was performed as proposed by Pereira

Table 4. Trends in formal errors dichotic test alternate dissyllable pre and post auditory training

SSW – Qualitative analysis	Pre		Post		p-value
	n	%	n	%	
Auditory effect A/B	0	0	0	0	- x -
Auditory effect B/A	1	11	0	0	0.303
Order effect A/B	4	44	0	0	0.023*
Order effect B/A	3	33	2	22	0.599
Inversions	2	22	0	0	0.134
Type A	0	0	0	0	- x -

* Significant values (p<0.05) - Wilcoxon test

Note: SSW = dichotic test alternate dissyllable, A/B = high/low, B/A = low/high

Table 5. Performance in RGDT test pre and post formal auditory training

RGDT	Pre	Post
Mean	12.17	9.64
Median	8.0	8.0
Standard deviation	11.37	7.08
Q1	5.5	5.0
Q3	12.5	10.0
n	9	9
CI	7.43	4.63
p-value	0.866	

Wilcoxon Test (p<0,05)

Note: RGDT = Random Gap Detection Test, Q1 = first quartile, Q3 = third quartile, CI = confidence interval

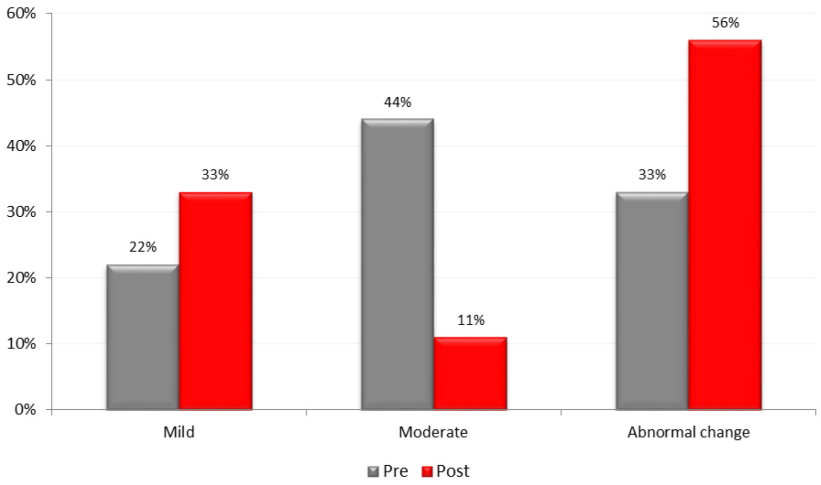

Figure 1. Grade rating of SSW pre and post formal auditory training

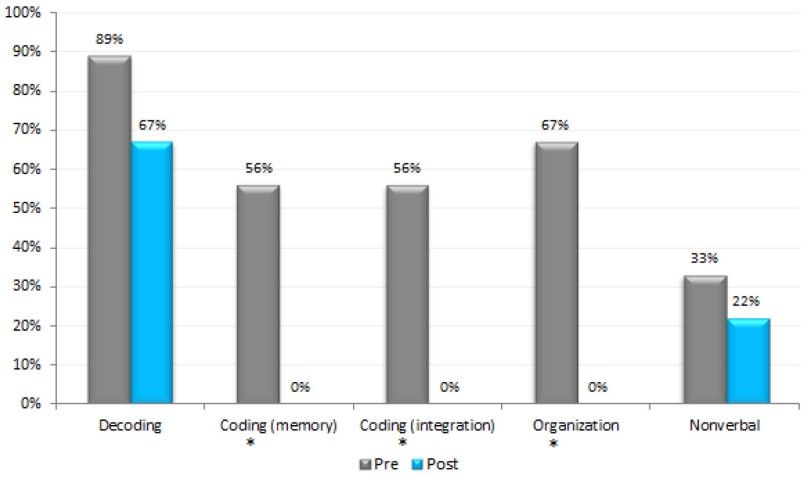

Figure 2. Ranked as the gnosis processes pre and post formal auditory training

(2004)[15]. The degree of TPA related to the difficulty / ease of communication of individuals in noisy environments. Thus, this result demonstrates that the FAT contributed to the communication of these individuals in adverse listening situations, such as in noisy and/or reverberant environments.

RGDT test (Table 5), found no significant difference, the average performance of subjects was changed to normal after FAT, showing suitability of auditory skill of temporal resolution, which related to phonological aspects and auditory discrimination[19].

The harmed gnosis processes (Figure 2), found that individuals had a lower incidence of all processes gnosis after FAT when compared with the initial evaluation, and the differences for encoding (gradual loss of memory and sensory integration) and organization were significant, showing improvements in memory, attention and organization respectively. There is improvement in three cognitive changes often found in individuals suffering from TBI as previously mentioned[26].

According to Figure 2, the change in decoding found in most patients after FAT, may be due to the limitation imposed by the injury reported by patients. Moreover, the goal of auditory training is not make normal tests quantitative point of view, but make individuals are better adapted and able to establish communicative exchanges more efficient daily.

According to one study[27], a heavy FAT, in order of increasing complexity tends to maximize the cortical plasticity and consequently results in learning. This was precisely the proposal of auditory training described in this study. Thus, these behavioral results demonstrated that the FAT led neuronal plasticity, reflecting on behavioral change. Several authors have demonstrated an improvement in auditory skills after FAT, from the change of the neural substrate, confirming findings of this research, suggesting the FAT as a tool for rehabilitation of central auditory disorders[10-13,21].

In this study, the revaluation performed after completion of training (about a week). Studies have shown that neural changes often precede behavioral[28,29], which suggests that achieving a longer follow-up (in terms of time) can bring further improvement of listening skills. When trained individuals exposed to activities with hearing demand, such as communicating in noisy environment, the environment itself is responsible for maintaining the enhanced listening skills and allows them to continue being perfected. Thus, it is important to educate patients after auditory training that you give to the various activities, especially those that were previously very difficult.

Authors[9] reported that a neural rehabilitation generate change, it can be said that the intervention strategy was successful. Thus, it can be said that, in this research, the FAT was effective in rehabilitating the central auditory abnormalities found in patients who have suffered TBI, in agreement with a study[14] showed improvement in symptoms, the behavioral and electrophysiological AP after auditory training in a patient who suffered mild TBI.

Neuronal plasticity in injured individuals occurs differently from those without brain injury. However, this study showed that the FAT was efficient in promoting neuronal plasticity by stimulation in patients after TBI, adapting listening skills and being able to compensate, even partially, cognitive, metacognitive and metalinguistic deficits, as cited by authors[2].

In addition to the data presented, suggest that behavioral improvements after FAT, subjects were asked about the benefits observed daily. The majority of subjects reported improvement, especially in attention and memory, not wanting treatment was discontinued.

Based on the data, it is important to evaluate the central auditory pathway of patients who suffered TBI, but also introduce them to a hearing rehabilitation program. Furthermore, it suggested that further studies conducted on patients with different degrees of severity and injury, to verify the need to evaluate them and rehabilitate them. Further research is necessary to conduct a follow-up enhances auditory skills and correlate with the language of these patients.

CONCLUSION

Individuals with diffuse axonal injury after suffering severe head trauma, feature adaptation of auditory figure-ground skills for verbal sounds, sorting and temporal resolution in the behavioral evaluation of auditory processing, after formal auditory training.

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