

Effects of auditory training in individuals with high-frequency hearing loss

Renata Beatriz Fernandes Santos, Andrea Tortosa Marangoni, Adriana Neves de Andrade, Raquel Prestes, Daniela Gil

Federal University of São Paulo, Speech Language Pathology Department, São Paulo/SP, Brazil.

OBJECTIVE: To determine the effects of a formal auditory training program on the behavioral, electrophysiological and subjective aspects of auditory function in individuals with bilateral high-frequency hearing loss.

METHOD: A prospective study of seven individuals aged 46 to 57 years with symmetric, moderate high-frequency hearing loss ranging from 3 to 8 kHz was conducted. Evaluations of auditory processing (sound location, verbal and non-verbal sequential memory tests, the speech-in-noise test, the staggered spondaic word test, synthetic sentence identification with competitive ipsilateral and contralateral competitive messages, random gap detection and the standard duration test), auditory brainstem response and long-latency potentials and the administration of the Abbreviated Profile of Hearing Aid Benefit questionnaire were performed in a sound booth before and immediately after formal auditory training.

RESULTS: All of the participants demonstrated abnormal pre-training long-latency characteristics (abnormal latency or absence of the P3 component) and these abnormal characteristics were maintained in six of the seven individuals at the post-training evaluation. No significant differences were found between ears in the quantitative analysis of auditory brainstem responses or long-latency potentials. However, the subjects demonstrated improvements on all behavioral tests. For the questionnaire, the difference on the background noise subscale achieved statistical significance.

CONCLUSION: Auditory training in adults with high-frequency hearing loss led to improvements in figure-background hearing skills for verbal sounds, temporal ordination and resolution, and communication in noisy environments. Electrophysiological changes were also observed because, after the training, some long latency components that were absent pre-training were observed during the re-evaluation.

KEYWORDS: Hearing; Hearing Loss; Auditory Perceptual Disorders; Hearing Tests; Hearing Impairment Correction.

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E-mail: renatabfsfono@yahoo.com.br

Tel.: 55 31 3344-7715

INTRODUCTION

It is possible to compensate for hearing loss with the use of hearing aids. However, these devices can distort sounds and the user often continues to have difficulty processing acoustic information, especially speech sounds in a noisy or reverberating environment (1).

In recent years, considerable advances have been made in hearing aid technology with the advent of digital devices that allow a wide range of programming and personalized settings.

However, the simple placement of hearing aids may not provide the hearing skills or understanding necessary for communication. Hearing aids are designed to provide the greatest possible amount of acoustic information, but they do not directly modify the user's brain or behavior (2).

While hearing aids are efficient for overcoming hearing loss, they do not help users overcome hearing problems stemming from auditory processing disorder (APD) (3). APD is a complex, heterogeneous group of hearing abnormalities often associated with a set of hearing deficits and normal auditory sensitivity (4). Moreover, some individuals only have hearing loss at high frequencies and a hearing aid does not adequately address the complaints of such individuals with regard to understanding speech in a noisy environment (5). Such individuals are often left with no treatment options and no hope for improvements in communication.

The ability of the auditory system to process acoustic signals can be optimized through auditory training therapy,

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which has been widely employed for individuals with APD (6-13). Auditory training constitutes a set of conditions and/or tasks designed to activate the auditory system and associated systems to allow beneficial changes in auditory behavior and in the central auditory nervous system (14).

Auditory-evoked potentials offer an advantage over traditional behavioral evaluations for assessing the progress of individuals undergoing therapeutic programs because neurophysiological changes stemming from therapy may occur prior to behavioral changes (15,16). A number of researchers have stated that changes in the neurophysiology of the central auditory nervous system following auditory training can be measured using short-latency and long-latency auditory-evoked potentials (15,16-18).

Self-evaluation questionnaires have also been used to help determine treatment plans and assess the efficacy of therapy from the patient's point of view (19). The Abbreviated Profile of Hearing Aid Benefit (APHAB) questionnaire addresses the benefits of hearing aid usage.

The aim of the present study was to determine the effects of a formal auditory training program on the behavioral, electrophysiological and subjective aspects of auditory function in individuals with bilateral high-frequency hearing loss.

■ METHOD

This study was conducted at the neuroaudiology and electrophysiology clinics of the Department of Hearing and Speech Therapy of the Federal University of São Paulo (Brazil). The inclusion criteria were age between 15 and 59 years, moderate symmetrical hearing loss beginning at 3000 Hz in both ears, at least 72% speech recognition bilaterally and no evidence of neurological or cognitive impairment. This study received approval from the university ethics committee. The participants received verbal information about the objectives and procedures of the study and signed a statement of informed consent agreeing to participate.

A brief clinical history was performed for each patient to acquire hearing data using a specific chart designed by the researcher. Evaluations were performed in two sessions, one to assess basic hearing and auditory processing (behavioral tests) and one to perform the electrophysiological evaluation and administer the APHAB questionnaire. The basic hearing evaluation included taking the patient's history and performing otoscopy, pure-tone threshold audiometry, logaudiometry, tympanometry and a contralateral acoustic reflex study.

The free-field evaluation of auditory processing involved the sound location test (SLT; 70-80 dB) and verbal and non-verbal sequential memory tests (70-90 dB). The other tests were performed in a sound booth using verbal and non-verbal stimuli recorded on a compact disc (CD) and delivered through earphones (TDH 50P) coupled to a two-channel audiometer (GSI-61, Grandson Stadler, Minneapolis, USA). The following tests were performed: the duration pattern test (DPT), the staggered spondaic word (SSW) test, synthetic sentence identification (SSI) with competitive ipsilateral competitive messages (ICM) and contralateral competitive messages (CCM), the random gap detection test (RGDT) and the speech-in-noise test (SNT). The tests came from the Central Auditory Processing Assessment Manual CDs (20), with the exceptions of the DPT (21) and RGDT (22).

Biologic Traveler equipment (Chicago Medical Equipment, Chicago, USA) was used and the preparation methods were the same as those used for auditory-evoked potentials testing. After the procedure was explained to the patient, the skin, cranial vertex and earlobes were cleaned with an abrasive paste and gauze. The inter-electrode impedance was equal to or less than 5 kOhms prior to the beginning of the test. The exams were performed in a silent room in partial darkness. The volunteer was instructed to remain still and relaxed with eyes closed throughout the auditory brainstem response (ABR) testing and with eyes opened during the long-latency auditory-evoked potential (LLAEP) testing (P300). For LLAEP, stimuli were presented using insertion earphones (ER-3) at an intensity of 80 dBHL with binaural presentation. The surface electrodes were attached with electrolytic paste (Ten20) and micropore adhesive tape to the forehead (ground electrode), cranial vertex (active electrode) and earlobes (reference electrodes), following the standard international system (23). The stimulus frequency was 1000 Hz and the rare stimulus was 2000 Hz, with appearance probabilities of 80% and 20%, respectively, presented using the "oddball" paradigm. Latencies were marked at the point of maximum wave amplitude (the largest peak). The amplitudes were marked from the peak of the wave to the baseline. Subtraction of the rare line gave rise to the wave form on which the latency and amplitude of the P3 component were marked. The recordings were smoothed.

To determine the ABR, the acoustic stimuli were clicks of rarefied polarity presented in only one ear at 80 dBHL. Two thousand stimuli on two recordings were used to ensure the reproducibility of the readings. The electrodes were placed on the forehead (ground electrode) and both earlobes (23). The absolute latencies of waves I, III and V and the I-III, III-V and I-V inter-peaks were analyzed.

Prior to and following auditory training, the participants responded to the APHAB questionnaire, which is a self-evaluation measure designed to quantify the disability associated with hearing loss and the reduction or non-reduction in disability resulting from hearing-aid use. Because no hearing aids were used in the present study, the APHAB was used for a subjective evaluation of the benefits of auditory training.

The volunteers underwent auditory training, which consisted of eight 45-minute sessions held once or twice a week, depending on the availability of each volunteer. The sessions were organized so that the activities increased in complexity to offer an increasing challenge to the auditory system throughout each session. Thus, the signal-to-noise ratio was adjusted from positive (easier) to negative (more difficult). The sessions included intensity, frequency and duration training for open-field sounds, figure-background hearing skills for verbal (phrases and numbers) and non-verbal sounds in dichotic hearing and auditory closure using earphones. The behavioral and electrophysiological evaluation results before and after training were compared.

The data were subjected to statistical analysis. The non-parametric Wilcoxon test was used to compare the results of the behavioral and electrophysiological evaluations and the APHAB before and after auditory training. Statistically significant findings based on the adopted significance level are highlighted in red or indicated with an asterisk (*). Findings with a tendency toward significance (approaching the acceptable limit: up to five percentage points above the



established alpha value) are highlighted in blue or indicated with a hash symbol (#). The significance level was set to 5% ($p < 0.05$) and 95% confidence intervals were calculated.

RESULTS

Seven individuals, 3 females (42.9%) and 4 males (57.1%), were evaluated. Their mean age was 52 years (range: 46 to 57 years). Two had a complete elementary school education, two had a complete high school education, one had not completed elementary school, one had not completed high school and one had a partial university education. All of the participants were right-handed and had hearing complaints, such as tinnitus, attention deficit and difficulty understanding speech in a noisy environment.

Based on the qualitative analysis of the electrophysiological evaluation, no significant change in ABR occurred following auditory training. All seven individuals had abnormal P300 (abnormal latency or the absence of the P3 component) at the pre-training evaluation and one individual had a normal P300 at the post-training evaluation. No significant differences were found between ears for the quantitative analysis of ABR or P300. Thus, the data from both ears were pooled. The same results occurred for the behavioral tests. Table 1 displays the quantitative data on the absolute latency of waves I, III and V and the I-III, III-V and I-V inter-peak intervals for ABR before and after auditory training. No significant differences were found between evaluation times.

No significant differences were found regarding the latency and amplitude of LLAEP-P300 between evaluations (Table 2). However, it is essential to emphasize that the patient who did not present a P3 wave during the pre-training evaluation presented this component during the re-evaluation right after the auditory training.

Figure 1 shows the performance of the individuals on the behavioral evaluation tests of auditory processing. The pre-training and post-training results are expressed as percentage values.

On the RGDT, the mean interval (in ms) of the frequencies necessary for the individuals to perceive two sounds was significantly lower at the post-training evaluation compared with the pre-training evaluation.

Moreover, reductions in the complaints on all subscales of the APHAB occurred at the post-training evaluation

Table 2 - Latency (ms) and amplitude (uV) of the P3 component of LLAEP-P300 before and after auditory training.

		Mean	Median	Standard deviation	N	CI	p-value
P300 Latency	Before	347.6	332.7	38.8	14	20.3	0.278
	After	339.6	336.7	27.5	14	14.4	
Amplitude	Before	4.13	3.35	2.92	14	1.53	0.422
	After	3.68	2.25	2.82	14	1.48	

Legend: N: number of individuals; CI: confidence interval; Wilcoxon test ($p < 0.05$).

compared with the pre-training evaluation (Figure 2). However, only the difference for the background noise subscale achieved statistical significance.

DISCUSSION

The present sample included both male and female adults, all of whom were right-handed. Because the participants were in the economically active age range, a lack of availability resulting from work-related issues explains the small number of subjects.

The qualitative analysis demonstrated differences in the electrophysiological evaluation (ABR and LLAEP-P300) following auditory training. Regarding ABR, despite the absence of substantial changes in the overall sample, one individual went from the abnormal to normal classification following auditory training and one went from a normal to an abnormal classification. All seven individuals had abnormal P300 waves at the pre-training evaluation and one individual had a normal P300 wave at the post-training evaluation. Moreover, the shape of the waves improved, which facilitated the identification of the components at the second evaluation. These data demonstrate that a neurophysiological change that could be measured objectively occurred following auditory training (11,12,15,17,25,26).

Regarding the quantitative analysis of ABR (Table 1), an increase in the latency of wave III that tended toward statistical significance was found after auditory training. This increase may be explained by the fact that one patient did not exhibit waves I or II bilaterally on the pre-training ABR, but these waves appeared in the left ear following

Table 1 - Absolute latency (ms) of waves I, III and V and the inter-peak intervals of ABR before and after auditory training.

ABR latency			Mean	Median	Standard deviation	N	CI	p-value
Latency	Wave I	Before	1.69	1.68	0.22	14	0.12	0.406
		After	1.73	1.71	0.20	14	0.11	
	Wave III	Before	3.90	3.88	0.18	14	0.09	0.092
		After	3.98	3.99	0.21	14	0.11	
	Wave V	Before	6.03	5.96	0.50	14	0.26	0.326
		After	6.07	6.10	0.36	14	0.19	
I-III inter-peak	Before	2.25	2.18	0.19	14	0.10	0.350	
	After	2.30	2.33	0.20	14	0.10		
III-V inter-peak	Before	2.03	2.00	0.19	14	0.10	0.592	
	After	2.05	1.95	0.20	14	0.10		
I-V inter-peak	Before	4.28	4.31	0.22	14	0.11	0.332	
	After	4.34	4.40	0.20	14	0.10		

Legend: N: number of individuals; CI: confidence interval; Wilcoxon test ($p < 0.05$).

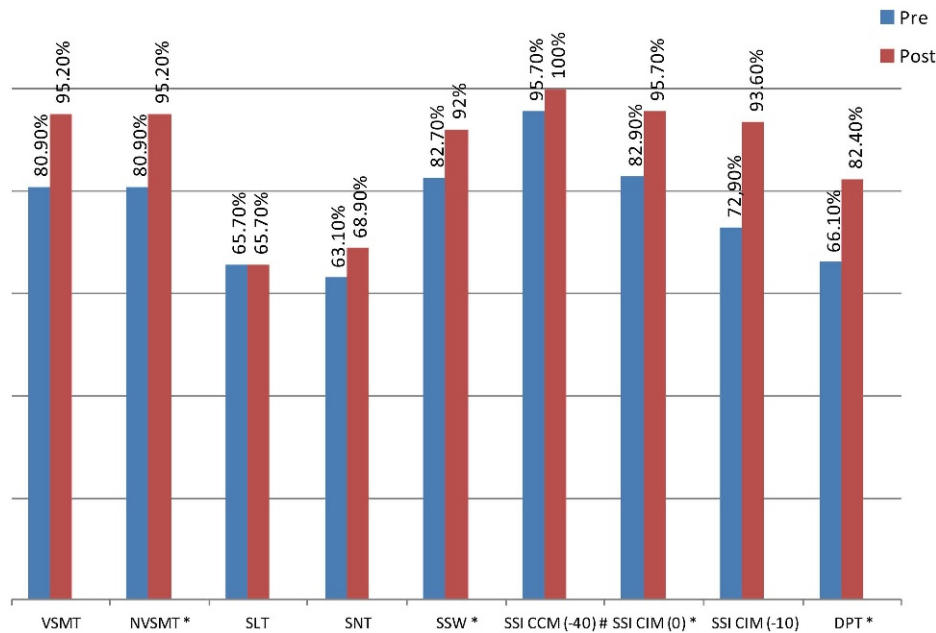


Figure 1 - Mean performance of individuals on behavioral evaluations of auditory processing before and after auditory training. Verbal sequential memory test (VSMT), Non-verbal sequential memory test (NVSMT), Sound location test (SLT), Speech-in-noise test (SNT), Staggered spondaic word (SSW) test, Synthetic sentence identification with competitive ipsilateral (SSI-ICM) and contralateral (SSI-CCM) competitive messages, Duration pattern test (DPT). Statistically significant (*); tending toward significance (#).

training. No statistically significant differences in amplitude were found between evaluation times.

Previous studies using LLAEP to evaluate neurophysiological changes following auditory training have reported improvements in amplitude, latency and/or wave shape after hearing stimulation. However, there is no consensus on whether amplitude or latency is more appropriate for confirming neuronal plasticity (17,18,24-27). In the present study, no significant difference in LLAEP-P300 was found with regard to either latency or amplitude (28). Despite the lack of statistically significant changes in short-latency and long-latency auditory-evoked potentials in the present study, one of the subjects did not exhibit P300 responses or waves I and III bilaterally on the ABR test during the pre-training evaluation, but LLAEP responses appeared bilaterally after auditory training and waves I and III appeared

for the left ear. These data indicate a qualitative improvement, thereby suggesting neuronal synchrony.

Regarding the analysis of performances on the behavioral tests of auditory processing (Figure 1), the participants demonstrated improvements on all tests except the SLT, with statistically significant improvements on the SSW (quantitative analysis), the SSI-ICM (0 and -10) and the DPT. Moreover, a tendency toward improvement was found for the non-verbal sequential memory test and the SSI-CCM (-40). These improvements can be attributed to auditory training; they demonstrate the generalization of the trained aspects to different contexts, as reported in previous studies (6,17). Moreover, the mean performance on the SSW, SSI-ICM (-10) and DPT tests went from abnormal to normal, demonstrating the adequacy of hearing skills for temporal ordination and figure-background for verbal sounds (words).

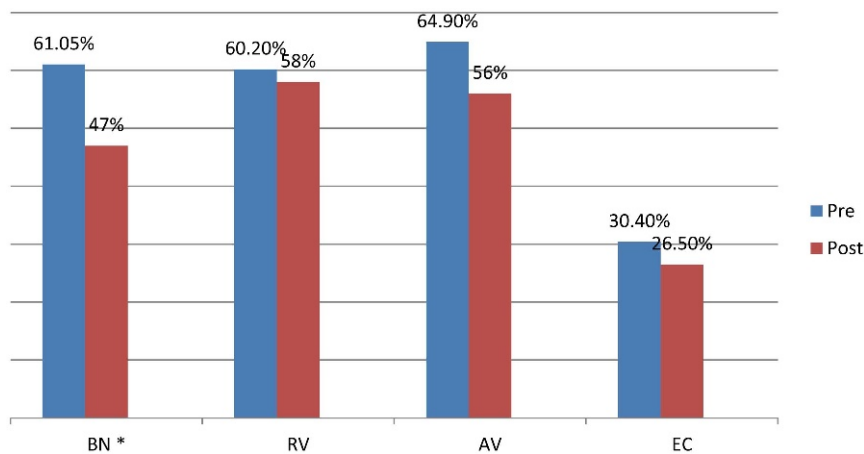


Figure 2 - Mean performance of individuals on each APHAB subscale before and after auditory training. Background noise (BN), Reverberation (RV), Aversiveness (AV), Ease of communication (EC). Statistically significant (*).



Previous studies have found improvements on all of these behavior tests following auditory training in different populations, such as individuals with APD, adult and elderly hearing aid wearers and victims of head trauma (25-29).

On the RGDT, the mean interval (ms) necessary for the individuals to perceive the presence of two sounds was significantly lower at the post-training evaluation compared with the pre-training evaluation. Thus, the participants' performance went from abnormal to normal following auditory training, and this change was related to phonological aspects and hearing discrimination. These data suggest an increase in processing efficiency and speed, which may contribute to improved communication in a noisy environment where acoustic cues are not completely available.

In the present study, the second evaluation occurred immediately following the end of the auditory training sessions. Studies have shown that neural changes often precede behavioral changes (11,12), which suggests that a longer follow-up time may reveal even greater improvements in hearing skills.

As stated above, it was not the aim of the present investigation to evaluate the maintenance of benefits acquired through auditory training. However, it is possible that once the neural substrate has been altered and the behavioral pattern has been learned, the environment and its demands may reinforce the learned pattern and even maintain a tendency toward improvement after the individual returns to his/her routine activities once the training sessions end. The literature offers reports of long-term follow-up periods in which the maintenance of gains and even a tendency toward improvement have been found (6,7). Other authors have stated that the maintenance of learned patterns depends on an individual's functional use of these patterns (17,24). Thus, these findings affirm that the auditory training proved effective at minimizing auditory processing difficulties among adults with high-frequency hearing loss.

No self-assessment tool specifically designed to quantify changes resulting from auditory training in individuals with high-frequency hearing loss was reported in the literature. Importantly, the APHAB was not used for its original purpose; rather, it was used to quantify the subjective impact of auditory training because there are no existing instruments designed for that purpose. The selection of this questionnaire was based on the fact that the APHAB has been adapted and validated in Portuguese (30). Moreover, this measure is considered a powerful tool for documenting the benefit of a given therapeutic approach because it is fast and easy to administer and easy to understand (31). In the present study, the participants showed improvements on all subscales, including a statistically significant improvement on the Environmental Noise subscale. Other authors reported similar results in a study involving adults with hearing aids (26). These data confirm the results of the behavioral tests, indicating an improvement in communication in noisy environments, as reported by the patients.

It is important to note the large number of complaints from individuals with preserved hearing at low and medium frequencies both before and after auditory training, especially among those who reported tinnitus. Improved communication in adverse environments should be the main goal of auditory training for individuals with hearing impairment and for those who have normal hearing but have APD because such environments are very common in

the daily lives of the majority of individuals, especially economically active adults.

Intensive auditory training with increasing complexity maximizes the plasticity of the brain cortex and generates learning (32). Because auditory training took place in this manner in the present study, the behavioral results demonstrate that the training enhanced neuronal plasticity, which was reflected in behavioral changes. A number of authors have reported improvements in hearing skills following auditory training as a result of changes in the neural substrate and the present data agree with those reports. These findings suggest that auditory training is an efficient rehabilitation tool for central hearing abnormalities, as studies have demonstrated that the central nervous system can be altered through auditory training (8,26,27,33).

In addition to the improvement measured by the tests applied, it should be stressed that the individuals reported improvements in their day-to-day living, especially with regard to attention. This finding is in agreement with previous studies (28,33,34) that found that both patients and family members reported improvements in daily living following auditory training, especially with regard to attention.

With the constant advances in technology, hearing aids are often effective for solving the problem of a loss of hearing sensitivity. However, hearing devices do not solve other hearing problems, such as difficulty with locating sounds and temporal processing and signal-to-noise ratio deficits (1,2,12,35). Thus, individuals with high-frequency hearing loss often have no treatment options to address their complaints and difficulties. It is therefore important to evaluate the central auditory pathway in such patients and place them in an auditory rehabilitation program, because hearing therapists should not overlook these patients. Moreover, further studies of auditory training involving long-term follow-up and the use of more specific self-evaluation tools should be conducted with these patients.

Based on the findings of the present study, auditory training in adults with high-frequency hearing loss leads to improvements in figure-background hearing skills for verbal sounds, temporal ordination and resolution, communication in noisy environments and changes in electrophysiological aspects (ABR and P300).

■ AUTHOR CONTRIBUTIONS

Santos RB was responsible for data collection and manuscript writing. Andrade AN, Marangoni AT and Prestes R were responsible for data collection. Gil D was responsible for data collection, manuscript writing and advising.

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