CLINICAL SCIENCE

FORMAL AUDITORY TRAINING IN ADULT HEARING AID USERS

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INTRODUCTION: Individuals with sensorineural hearing loss are often able to regain some lost auditory function with the help of hearing aids. However, hearing aids are not able to overcome auditory distortions such as impaired frequency resolution and speech understanding in noisy environments. The coexistence of peripheral hearing loss and a central auditory deficit may contribute to patient dissatisfaction with amplification, even when audiological tests indicate nearly normal hearing thresholds.
OBJECTIVE: This study was designed to validate the effects of a formal auditory training program in adult hearing aid users with mild to moderate sensorineural hearing loss.
METHODS: Fourteen bilateral hearing aid users were divided into two groups: seven who received auditory training and seven who did not. The training program was designed to improve auditory closure, figure-to-ground for verbal and nonverbal sounds and temporal processing (frequency and duration of sounds). Pre- and post-training evaluations included measuring electrophysiological and behavioral auditory processing and administration of the Abbreviated Profile of Hearing Aid Benefit (APHAB) self-report scale.
RESULTS: The post-training evaluation of the experimental group demonstrated a statistically significant reduction in P3 latency, improved performance in some of the behavioral auditory processing tests and higher hearing aid benefit in noisy situations (p-value < 0,05). No changes were noted for the control group (p-value <0,05).
CONCLUSION: The results demonstrated that auditory training in adult hearing aid users can lead to a reduction in P3 latency, improvements in sound localization, memory for nonverbal sounds in sequence, auditory closure, figure-to-ground for verbal sounds and greater benefits in reverberant and noisy environments.

KEYWORDS: Hearing loss; Rehabilitation; Auditory Evoked Potentials; Neuronal Plasticity.

INTRODUCTION

Sensorineural hearing loss is characterized by an elevation of pure tone thresholds and often, difficulty understanding speech, especially in noisy environments. For most patients, hearing aids are effective tools for overcoming sensitivity loss, especially when they incorporate recent technological developments. However, hearing aids are not always capable of helping the patient compensate for difficulties in understanding speech, particularly in a reverberant and/or noisy environment.[1] Even the most sophisticated hearing aids are unable to improve auditory skills or the comprehension needed for efficient communication. Hearing aids provide increased acoustic information, but alone they are not able to directly modify the brain or the patient's behavior.[2] Furthermore, peripheral hearing loss may coexist with a central auditory processing deficit, thereby contributing to patient dissatisfaction with amplification, even when audiological tests indicate nearly normal aided hearing thresholds.

Auditory training has been highlighted as part of habilitation/rehabilitation for the hearing impaired, though it has been underutilized. It is primarily based on the belief that the peripheral system benefits from the stimulation provided. However, advances in neuroscience suggest that it is the central auditory system that benefits from auditory stimulation.[2-4] A number of authors have concluded that the auditory processing evaluation of hearing aid candidates/users provides a more complete profile of auditory skills and may be useful in choosing between different amplification options and complementary

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remediation tools.[3,5,6] Therefore, auditory processing tests could contribute to and complement the classical peripheral auditory evaluation. Detailed clinical research in this area is crucial to determining the best approach and technique so as to achieve maximum success with a rehabilitation program. Unfortunately, there do not appear to be any studies in the literature that involve behavioral and electrophysiological measurements of central auditory processing, formal auditory training and self-assessment outcome measures in adult hearing aid users.

The aim of this study was to examine the effects of formal auditory training on adult binaural hearing aid users with mild to moderate bilateral sensorineural hearing loss using the following three procedures: behavioral tests of auditory processing, long-latency auditory evoked potentials and a self-assessment questionnaire.

Behavioral tests of auditory processing were employed to identify and monitor any changes in the central auditory system as a result of the auditory training program. Long-latency auditory evoked potentials (LLAEP) were used to plan and monitor rehabilitation outcomes in specific populations. Since LLAEPs are not influenced by the presence of hearing loss, especially in mild and moderate hearing losses, hearing-impaired subjects may be accurately evaluated with this procedure. Finally, the inclusion of a self-assessment questionnaire provided the basis for evaluating the success or failure of the auditory training program from an important, objective source – the patient.

MATERIALS AND METHODS

All subjects in this double-blind, randomized study met the following inclusion criteria:

- Age between 16 and 60 years old.
- Mild to moderate bilateral sloping sensorineural hearing loss.
- Symmetric pure-tone thresholds.
- Symmetric word recognition scores of 72% or more.
- Binaural intra-aural hearing aid users for at least three months.
- No other diagnosed disorders, such as neurological, psychological, cognitive or mental disturbances.

Fourteen subjects were randomly divided into two equal groups: an experimental group (with auditory training) and control group (without auditory training). Aided hearing thresholds ranged from 15 to 35 decibels (dB) for all subjects with the pure tone average (500, 1000 and 2000 Hz) at 35 decibels hearing level (dB HL) or better. This study was approved by the Ethical Committee in Research of the Universidade Federal de São Paulo, number 0685/05.

All subjects, regardless of group placement, received a behavioral auditory processing evaluation and an electrophysiological evaluation and were asked complete a self-assessment questionnaire, the Abbreviated Profile of Hearing Aid Benefit (APHAB). These procedures were performed before and after the auditory training for the experimental group and at times coinciding with the beginning and end of the study for the control group. In order to characterize this project as a double-blind study, the examiner who performed the second evaluation did not know whether the subject belonged to the experimental or control group and was unaware of the results of the subject's first test procedures.

Behavioral auditory processing evaluation

The behavioral auditory processing evaluation was carried out with headphones while subjects wore their hearing aids, since all of them were fitted with in-the-ear (ITE) hearing aids. As central auditory processing evaluation in hearing aid subjects is a controversial issue, tests were included that have been shown to be more robust in the presence of peripheral auditory damage.[5,7] The test battery was designed to ensure maximum use of clinician time during administration as well as to limit the time a subject was exposed to testing procedures, thus offering subjects an optimal opportunity to do well. Based on these design elements, the following procedures were selected:

1. Sound localization: the patient was instructed to identify the origin of the instrumental sound in five directions (right, left, above the head, in front of the head and behind the head) with her/his eyes closed.
2. Memory for verbal sounds in sequence: the patient was instructed to repeat the syllables PA, TA, CA, FA in three different sequences without any visual clues.
3. Memory for nonverbal sounds in sequence: the patient was asked to reproduce three sequences of four instrumental sounds without any visual clues.
4. Word recognition score with recorded stimuli: two lists of 25 recorded monosyllables were presented to each ear separately, and the patient was asked to repeat each of them.
5. Speech-in-noise test: two different lists of 25 monosyllables were presented to each ear in the presence of ipsilateral white noise using a signal-to-noise ratio (SNR) of +5, and the patient was asked to repeat each monosyllable while ignoring the noise.
6. Synthetic Sentence Identification (SSI): the patient was instructed to point to the sentence presented in the headphones on a chart displayed in front of him/her while ignoring the competitive stimuli represented by a verbal discourse. This test was performed in the dichotic and

monotic conditions.

7. Dichotic Digits – Binaural Integration Condition: the patient was asked to repeat twenty series of four digits presented dichotically.

All tests, except sound localization and memory for verbal and nonverbal sounds in sequence, which were performed in a sound field using musical instruments, were performed using recorded stimuli from a commercially available Brazilian Compact Disc (CD)[8]. All procedures were previously standardized for clinical use in Portuguese. As the subjects of our study exhibited nearly normal aided hearing thresholds, their performance was compared to the expected levels for subjects with normal hearing.

Electrophysiological Evaluation

The electrophysiological evaluation in this study consisted of measures of Long-Latency Auditory Evoked Potentials – N1, P2, N2 and P3, registered without hearing aids using an odd-ball paradigm with tone bursts. The frequent and rare stimuli were 1000 Hz and 2000 Hz tones with 80% and 20% of probability, respectively. The intensity level varied from 70 to 85 dB HL, according to the residual hearing in the test frequencies involved.[9] A four-channel Biologic Systems unit was used to measure the LLAEP recordings. Surface electrodes were affixed according to the following montage: Fpz= ground – forehead; Cz=active electrode – vertex; A1= left ear lobe; and A2= right ear lobe. Inter-electrode impedance of 5 Kohms or less was guaranteed during the entire recording. Subjects were asked to lie still with their eyes closed while silently counting the number of "different" (rare) stimuli. A 5-minute training session was allowed for each subject. The latencies and amplitudes of the N1, P2 and N2 components were marked in the rare tracings. The subtraction of rare from frequent tracings created a waveform from which P3 latency and amplitude were determined.

Self-assessment questionnaire

The APHAB was used to study the subjective effectiveness of the auditory training.[10] This instrument has been translated and validated in Portuguese.[11] APHAB is a self-assessment questionnaire used to quantify auditory difficulties experienced in daily situations involving communication in quiet, noisy and reverberant environments. It also reflects aversion to certain sounds. It is usually administered before and after fitting amplification as a mechanism to verify the benefit provided by hearing aids. All subjects completed an APHAB in two different situations, before and after auditory training in the experimental group, and as initial and final evaluations in the control group. As subjects were already wearing hearing aids in both situations, patients were asked to answer the questionnaire using only the column corresponding to "with hearing aids".

Formal Auditory Training Program

Our formal auditory training program was organized into eight one-hour sessions, held twice a week for four weeks. All sessions were performed with hearing aids and designed to provide intensive stimulation and challenge the auditory system. For these purposes, the SNR was varied from positive (easier) to negative (more difficult) during each activity that involved ignoring competitive stimuli. During monaural activities, such as temporal processing training, the stimuli level was constant. Activities involved pointing to sentences, figures, digits, verbal repetition and humming temporal patterns.

Right and left ears were trained separately in an attempt to compensate for interaural differences usually observed in behavioral auditory processing tests, except during binaural integration activities and temporal processing training, when sound field presentation was used. The stimulation paradigm of each ear was as follows: the intensity level was fixed for the ear under training while the contralateral intensity level was increased (SNR from positive to negative), and the patient's task was to pay attention to the stimuli delivered to the ear under training while ignoring the contralateral messages. This paradigm is similar to one known as Dichotic Interaural Intensity Difference (DIID)[12] that was proposed by an American audiologist. In order to keep the patients motivated, a 70% correct response rate was required at each step of the training before the patient was permitted to advance to another activity. After each session, the patient's performance was discussed with the examiner. Positive aspects were emphasized. Table 1 summarizes the formal auditory training (FAT) schedule employed in the present study.

RESULTS

All data obtained from the behavioral central auditory processing test battery, electrophysiological evaluation and APHAB were statistically analyzed. To investigate the effects of the FAT program, the Student t-test was used to compare the performance variance of subjects from both control and experimental groups, in both evaluations (pre- and post-training), considering behavioral auditory processing tests, the electrophysiological test and the APHAB. The significance level was set at 5% ($p = 0.05$), and confidence intervals were established at 95%. Significant

Table 1 - Formal Auditory Training (FAT) Schedule

Session	Test	Auditory Skill	Stimulation Pattern	Ear
1 and 2	Synthetic Sentences Nonverbal Dichotic Test	Figure to ground for sentences and nonverbal sounds	+20 to –20 +10 to –40	LE/RE RE/LE
3 and 4	Dichotic Digits	Figure to ground for digits	+20 to –20	LE/RE
5	Duration Pattern	Temporal Ordering	Sound Field Musical Tones	RE+LE
6	Duration And Frequency Pattern	Temporal Ordering	Duration Pattern - Earphones Frequency Pattern – musical tones – sound field	RE + LE RE/LE
7	Frequency Pattern	Temporal Ordering	Pure tones – earphones	RE/LE
8	Speech in noise (Sentences)	Auditory Closure	+25 to +5	RE/LE

values are highlighted by the symbol (*), and tendency toward statistical significance values are highlighted by the symbol (#).

Table 2 shows the amount of improvement in behavioral auditory processing tests of the control group comparing pre- and post-training evaluations. No significant differences in performance were observed for the majority of behavioral tests, expect for SSI-ICM SNRs -10 and -15, which revealed better results post-training.

Table 3 shows the amount of improvement in behavioral auditory processing tests of the experimental group by comparing pre- and post-training evaluations. Significant differences in performance of the experimental group were observed when comparing the tests results pre- and post-training, demonstrating improved performance following training.

Table 4 (Variation in latency and amplitude values of LLAEP for the control group when pre- and post-training evaluations were compared) shows that significant differences were observed for the latencies of P2 and N2 LLAEP components. For P2 an increase in latency was observed, while for N2 a decrease in latency was verified when comparing pre- and post-training evaluations. No variations were noted in the amplitudes.

In Table 5 (Variation in latency and amplitude values of LLAEP of the experimental group when comparing pre- and post-training evaluations) it is easily seen that for the experimental group, a significantly lower latency was observed for the P3 component of LLAEP when comparing pre- and post-training evaluations. As with the control group, no significant differences were seen concerning latency.

Finally, in Table 6 (Benefit observed in APHAB of control and experimental groups when comparing pre- and post-training administration), we present the comparison of benefit observed through the administration of the APHAB to the control and experimental groups. No differences were noted for the control group, while there was a trend toward statistical significance for the experimental group in the reverberation and background noise sub-scales.

DISCUSSION

Six behavioral auditory processing tests were used to evaluate the participants. All patients exhibited abnormal

Table 2 - Amount of improvement in behavioral auditory processing tests for the control group when comparing pre- and post-training evaluations

Control	**SL**	**MVS**	**MNVS**	**WRS**	**SIN**	**DD**	**CCM SSI**	**ICM SSI**	**SSI-10**	**SSI-15**
Mean	2,9%	0,0%	0,0%	-2,0%	-5,1%	4,6%	3,6%	2,9%	7,9%	15,7%
Median	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	5,0%	0,0%
SD	7,6%	19,2%	19,2%	7,8%	11,1%	16,8%	16,5%	11,4%	9,7%	21,7%
VC	265%	- x -	- x -	-390%	-217%	362%	461%	399%	124%	138%
Min	0,0%	-33,3%	-33,3%	-20,0%	-24,0%	-22,0%	-40,0%	-20,0%	0,0%	0,0%
Max	20,0%	33,3%	33,3%	12,0%	8,0%	42,0%	30,0%	30,0%	30,0%	50,0%
N	7	7	7	14	14	14	14	14	14	14
CI	5,6%	14,3%	14,3%	4,1%	5,8%	8,8%	8,6%	6,0%	5,1%	11,4%
p-value	0,356	1,000	1,000	0,355	0,108	0,321	0,431	0,365	0,010*	0,018*

Legend: SL= sound localization; MVS= memory for verbal sounds in sequence; MNVS= memory for nonverbal sounds in sequence; WRS= word recognition score with recorded stimuli; SIN= speech-in-noise test; DD= dichotic digits test; SSI= synthetic sentences identification test; CCM= contralateral competitive message; ICM= ipsilateral competitive message; SD= standard deviation; VC= variation coefficient; CI= confidence interval.

Table 3 - Amount of improvement in behavioral auditory processing tests for the experimental group comparing pre- and post-training evaluations

Experimental	SL	MVS	MNVS	WRS	SIN	DD	CCM SSI	ICM SSI	SSI-10	SSI-15
Mean	17,1%	18,1%	22,9%	2,0%	12,9%	7,3%	1,4%	17,1%	36,4%	68,6%
Median	20,0%	0,0%	33,3%	4,0%	10,0%	3,0%	0,0%	20,0%	40,0%	70,0%
SD	13,8%	37,5%	15,8%	7,8%	15,7%	11,3%	3,6%	13,3%	16,0%	23,5%
VC	81%	207%	69%	390%	122%	156%	254%	77%	44%	34%
Min	0,0%	-33,3%	0,0%	-12,0%	-12,0%	-1,0%	0,0%	0,0%	0,0%	20,0%
Max	40,0%	66,7%	33,3%	12,0%	48,0%	42,0%	10,0%	40,0%	60,0%	100%
N	7	7	7	14	14	14	14	14	14	14
IC	10,2%	27,7%	11,7%	4,1%	8,2%	5,9%	1,9%	6,9%	8,4%	12,3%
p-value	0,017*	0,248	0,009*	0,355	0,009*	0,032*	0,165	<0,001*	<0,001*	<0,001*

Legend: SL= sound localization; MVS= memory for verbal sounds in sequence; MNVS= memory for nonverbal sounds in sequence; WRS= word recognition score with recorded stimuli; SIN= speech-in-noise test; DD= dichotic digits test; SSI= synthetic sentences identification test; CCM= contralateral competitive message; ICM= ipsilateral competitive message; SD= standard deviation; VC= variation coefficient; CI= confidence interval.

Table 4 - Variations in latency and amplitude values of LLAEP for the control group when comparing pre- and post-training evaluations

Control	Latency				Amplitude			
	N1	**P2**	**N2**	**P3**	**N1**	**P2**	**N2**	**P3**
Mean	-0,21	12,86	5,60	6,43	-0,18	-0,01	0,13	0,41
Median	0,0	5,0	7,0	1,0	0,0	0,0	0,0	0,0
SD	4,3	16,6	5,1	16,5	0,7	0,3	0,5	1,2
VC	-2023%	129%	90%	257%	-375%	-2787%	355%	286%
Min	-10,0	0,0	0,0	-20,0	-1,4	-0,9	-0,3	-1,1
Max	6,0	56,0	12,0	44,0	1,0	0,4	0,9	3,6
N	14	14	10	14	14	14	9	14
CI	2,3	8,7	3,1	8,7	0,4	0,2	0,3	0,6
p-value	0,856	0,012*	0,007*	0,169	0,356	0,936	0,403	0,223

Legend: LLAEP= Long-Latency Auditory Evoked Potential; SD= standard deviation; VC= variation coefficient; CI= confidence interval.

Table 5 - Variation in latency and amplitude values of LLAEP for the experimental group when comparing pre- and post-training evaluations

Experimental	Latency				Amplitude			
	N1	**P2**	**N2**	**P3**	**N1**	**P2**	**N2**	**P3**
Mean	-0,71	8,43	15,08	-27,00	-1,73	-0,06	-0,98	0,21
Median	1,0	-7,0	-4,0	-18,0	-0,3	0,1	-0,4	-0,1
SD	12,8	29,4	68,1	39,3	4,4	1,8	2,5	2,7
VC	-1793%	349%	451%	-146%	-252%	-2919%	-255%	1283%
Min	-24,0	-16,0	-94,0	-110,0	-9,1	-3,5	-6,1	-3,5
Max	30,0	78,0	146,0	16,0	3,4	3,0	2,2	5,9
N	14	14	12	12	14	14	12	14
CI	6,7	15,4	38,5	22,3	2,3	0,9	1,4	1,4
p-value	0,838	0,303	0,459	0,037*	0,162	0,895	0,202	0,777

Legend: LLAEP= Long-Latency Auditory Evoked Potential; SD= standard deviation; VC= variation coefficient; CI= confidence interval.

Table 6 - Benefit observed in APHAB for control and experimental groups comparing pre- and post-training administration

APHAB	Experimental				Control			
	EC	RV	BN	AV	EC	RV	BN	AV
Mean	-4,9%	-4,6%	-8,0%	-3,7%	2,0%	-0,4%	3,6%	1,0%
Median	-6,0%	-6,0%	-13,0%	0,0%	2,0%	0,0%	4,0%	2,0%
SD	12,2%	6,1%	10,1%	7,5%	7,9%	7,8%	9,1%	7,3%
VC	-251%	-134%	-126%	-202%	397%	-1822%	253%	730%
Min	-19,0%	-13,0%	-21,0%	-20,0%	-11,0%	-12,0%	-14,0%	-13,0%
Max	16,0%	4,0%	4,0%	1,0%	15,0%	10,0%	12,0%	8,0%
N	7	7	7	7	7	7	7	7
IC	9,0%	4,5%	7,5%	5,6%	5,9%	5,8%	6,7%	5,4%
p-value	0,332	0,095#	0,080#	0,238	0,530	0,889	0,337	0,730

Legend: APHAB= Abbreviated Profile of Hearing Aid Benefit; EC= ease of communication; RV= reverberation; BN= background noise; AV= aversiveness of sound; SD= standard deviation; VC= variation coefficient; CI= confidence interval.

results on at least one of the tests during the pre-training evaluation. Thus, everyone demonstrated auditory difficulties with degraded stimuli, as previously reported in different studies.[1,13,14] Auditory difficulty could not be predicted by either functional gain or word recognition scores in quiet, as results were within normal limits under such conditions. Prior to the auditory training program, performance in the control group was generally poorer than in the experimental group

The limited amount of improvement in behavioral tests by the control group (Table 2) suggest that all behavioral tests used, except SSI-ICM (-10 and -15), were of minimal value. Interestingly poorer results were seen during the post-training evaluation after some tests, including word recognition scores and the speech in noise test.

When considering SSI-ICM (-10 and -15), significant differences were observed between pre- and post-training evaluations. This improvement, although insufficient to explain the results completely, could be attributed to patients' familiarity with the procedure leading them to ignore the competitive message while focusing on the target sentence. This has occurred in one previous study, where the control groups, without training, showed some improvements during the re-evaluations.[15] However, these improvements were not of the same magnitude as those observed in the groups which underwent auditory training.

The performance of the experimental group during the post-training evaluation was better than the first evaluation (Table 3), since the comparison between post- and pre-training performance resulted in positive values for all tests. Statistically significant differences were observed in sound localization, memory for nonverbal sounds in sequence, the speech in noise test, dichotic digits and SSI-ICM (0, -10, -15), with SSI-ICM (-15) demonstrating an improvement of almost 70%.

This is interpreted to mean that formal auditory training was effective in improving central auditory skills.[16-18] The post-training evaluation of the experimental group was within established limits for adults with normal hearing.

When sound is introduced into an impaired auditory system, spectral and temporal cues in the central auditory nervous system are altered. As a result, patients are forced to combine different spectral and temporal codes as they remember speech sounds. Failure to do so culminates in difficulties in understanding, especially in situations with ambient noise. This was confirmed by the results of the present study during the speech in noise test, in which the subjects' performance was negatively influenced by the introduction of noise. The stimuli were the same in both quiet and noise; only the order of presentation was changed. The results indicate that amplification provided by the hearing aids was insufficient to maintain the same quality in both quiet and noisy environments (Table 2). However, this auditory skill may be improved with auditory training (Table 3). Finally, it is possible that hearing aid fitting alone fails to produce the ideal environment for the auditory system and its skills.[2,6,19,20] When a central auditory processing disorder co-exists with peripheral hearing loss, compensation obtained from hearing aids is at times insufficient to compensate for the auditory processing disorder (APD), and the patient may become dissatisfied and frustrated with the performance of the hearing aids.[2,19] Based on our results, auditory processing evaluations should seriously be considered during the hearing aid fitting process.

Although there were no significant differences between right and left ears for either group on any of the experimental measures, individual results for some patients in both the control and experimental groups demonstrated asymmetrical results in central auditory processing tests, such as dichotic digits, speech in noise and SSI-ICM. Such differences were minimized for subjects in the experimental group after the completion of training. The phenomenon of binaural interference is suspected when performance in speech tests with binaural amplification is worse than with monaural or without hearing aids.[4,6,21-23] In cases of binaural interference, a unilateral hearing aid fitting is advisable. It is important to consider that in the case of a monaural fitting, the unaided ear may suffer the deleterious effects of sensory deprivation, affecting neural plasticity and leading to a progressive degradation of word recognition on the non-aided side. This can occur even when auditory thresholds are stable.[14,24]

As discussed above, one could question whether it would be more reasonable to document asymmetry in a patient with a central auditory processing disorder and then fit both ears to maximize the advantages of binaural hearing. After waiting a reasonable acclimatization period, the patient would be enrolled in a formal auditory training program, at the end of which the decision would be made as to whether a binaural or a monaural hearing aid fitting is more suitable.

One of the most controversial aspects of formal auditory training is the use of the same test for training and evaluation. It has been suggested that this runs the risk of "training for the test", thereby resulting in a positive bias during re-evaluation. Nonetheless, our results suggest that generalization in non-trained contexts is possible since, in the tests used only for evaluation, including sound localization, memory for verbal and nonverbal sounds and the speech in noise tests, objective and subjective measures showed improved results for the experimental group after training. Such results can be attributed to the auditory training with a considerable degree of confidence. Generalization for non-trained situations has been mentioned in several previous studies.[16, 25-28]

The maintenance of any learned pattern depends on its use.[27,29] Therefore, it seems reasonable to conclude that benefits accrued from the auditory training program will be maintained if the patient continues to use what he or she has learned. However, future studies are needed to determined if this is the case.

Concerning LLAEP, the N1-P2-N2 and P3 complexes were identified in all patients from both the control and experimental groups, and all subjects exhibited latency values within normal limits. These results concur with those of previous authors, who have noted that the presence of peripheral hearing loss, especially to mild and moderate degrees (which is the case in this study), does not prevent the registration of late potentials, since the patient is able to perceive both rare and frequent stimuli.[30-32] However, also mentioned in other studies is considerable inter-subject variability for both latency and amplitude values.[15,27,37]

Statistical analysis revealed no significant differences between right and left ears. Since both ears were considered in the study, statistical analysis was made more reliable, as the sample size was doubled.

The control and experimental groups did not differ with regard to LLAEP components in latency or amplitude in the first evaluation.

However, when comparing the variation in latencies values between pre and post training evaluations of the control Group (Table 4), significant changes were observed for P2 and N2 latencies. The P2 component showed an increase in latency of 12.86 ms, while a decrease of 5.60 ms was observed for the N2 component. The N1-P2-N2 complex of LLAEP is influenced by attention.[9] If the target stimulus is ignored, waveforms may be attenuated, and possible delays in latency may be observed. The contrary is also true.

For the experimental group, a statistically significant reduction in P3 latency (27 ms) was observed when comparing latency between the pre- and post-training electrophysiological evaluation (Table 5). Although no statistical differences were demonstrated in P3 latency for the control group, a slight increase in latency of 6.43 ms was noted (Table 4).

Latency reduction of evoked potentials after auditory training has been described as a neurophysiologic correlate of neural plasticity. In many cases, this change may precede a behavioral change, which could take longer since it requires the integration of neural modifications and conscious perception and also involves higher cognitive processes.[15,33,34] Furthermore, latency reduction may be understood as an improvement in electrophysiological function. This improvement may be attributed to the auditory training, as the training was carried out after the acclimatization period.[11,14,35,36] Finally, as an objective measure of neural change, the improvement appears to influence neural plasticity in adults, as mentioned in a number of other studies.[6,28,29,34,37-39]

Since the importance of temporal aspects in maximizing auditory skills is well recognized, the latency reduction observed in the experimental group may be of critical importance for improving communication for hearing aid users, especially in adverse environments. This improvement, along with advanced hearing aid technology, may help patients in daily situations, leading to improved use of hearing aids and better social integration.

No statistically significant differences were observed in the variation of amplitude between the pre- and post-training evaluations for both groups (Tables 4 and 5). The increase in amplitude, especially of P3 after auditory training, suggests better synchrony in neural firing and attention improvement and has also been shown to be related to neural plasticity.[15,27,28,34,38,40]

There is still controversy regarding which parameter, latency or amplitude, is the better indicator of neurophysiologic improvement when determining the efficacy of a specific therapeutic approach.[33] We conclude that amplitude, as measured in the present study, does not allow for inferences about the efficiency of the auditory training program described here. Our results were the same as those previously noted in different studies in the literature.[27,28,31,38]

The results from this portion of the study suggest that the behavioral and electrophysiological improvements observed in the experimental group after training support central changes and improved functioning and highlight the importance of establishing the interaction between the central auditory nervous system and amplified sound, as previously recommended.[3-6,39]

The APHAB self-assessment questionnaire was selected to help determine whether the expected/observed changes in electrophysiological and behavioral evaluations would interfere with the patient's subjective evaluation. There does not appear to be a specific self-assessment questionnaire designed to quantify changes observed in adult hearing aid users following a specific auditory training program. However, APHAB has been shown to be a powerful instrument for recording the benefit of a specific therapeutic approach.[41] Thus, we felt it the most appropriate self-assessment questionnaire for our study.

Self-assessment questionnaires have played a very important role in the validation stage of hearing aid fitting, as they reveal the benefits perceived in daily situations with amplification.[35] The similarity of responses for both groups regarding the ease of communication sub-scale (EC) indicates that the patients were well-adapted to their hearing aids, mainly in silent environments and/or in conversations involving small groups in relatively quiet places. However, the vast majority complained of difficulties hearing in noisy environments (Table 6). Some admitted they removed their hearing aids in such environments. This strategy frequently put them in embarrassing situations, leaving them feeling uncomfortable with their hearing aids in and missing important parts of conversations, dialogues and lectures without them.

As the subjects in our study wore hearing aids in both situations when answering the APHAB, the magnitude of benefit should not be the same as was seen during the original application of this instrument. No significant differences were observed in the control group at all sub-scales, when comparing the first and second applications. This suggests that reported difficulties remained stable, as previously reported.[42] However for the experimental group, communicating in noisy and reverberant environments was easier than before the training.

Table 6 shows the comparison of percentage of difficulties experienced by the participants in the sub-scales of APHAB for both applications of the questionnaires, pre- and post-training. Although the differences observed in the experimental group in reverberation and background noise sub-scales only trended toward statistical significance, all sub-scales revealed negative values, indicating that after auditory training participants in the experimental group reported fewer difficulties in daily situations. This means that communication in adverse environments became easier for the experimental group following auditory training. In another study, 90% of adult hearing aid users felt more capable and more confident in challenging auditory situations after auditory training with a commercial available CD-ROM.[2]

The opposite occurred in the control group, where positive values were seen in the ease of communication, background noise and averseness to loud sound sub-scales (Table 6).

Improvements for the experimental group were previously noticed in electrophysiological and behavioral evaluations (Tables 2 to 5).

Although subjects in both groups were similar in peripheral hearing status and hearing aid technology, environmental differences are expected and may account for differences in subjective measures such as self-assessment questionnaires.

Communication improvement in noisy environments should be the primary goal of any auditory training program, especially since such environments are common in everyday life. A hearing aid fitting would likely effectively compensate for the loss of sensitivity. However, there is still the chance of having a subject whose hearing thresholds have been made normal but who has an auditory processing disorder. Such a patient would not complain of difficulties in receiving sounds but rather in interpreting them, especially in the presence of increasing noise. It is suggested that administering an auditory training program, as described in the present study, and a self-assessment questionnaire, such as the APHAB, could make the assessment and identification of hearing-impaired patients with an additional auditory processing disorder easier.

CONCLUSIONS

The results of the present study suggest that formal auditory training was able to improve the central auditory skills of hearing aid users. Improvement was noted in an objective neurophysiologic correlate and perceived by patients, as revealed in a self-assessment questionnaire. Therefore, we strongly advocate investing time searching for the presence of a central auditory processing disorder during the course of all hearing aid fittings. Furthermore, programs for rehabilitation of these skills are essential for all patients identified, regardless of age.

In many cases, the high cost of hearing aids prevents patients from acquiring them, particularly if the patient feels that the benefit will not outweigh the high cost of the investment. Including an initial auditory processing evaluation and formal auditory training should provide a basis for such patients to feel more confident about purchasing a sophisticated and expensive hearing aid. Audiologists play an important role in this situation by helping patients realize the importance of auditory training and introducing it as a part of the hearing aid fitting process.

After a critical analysis of the results, we can conclude that formal auditory training in adult hearing aid users promotes:

Latency reduction of the P3 component of LLAEP.

Improvement in auditory skills for sound localization, memory for nonverbal sounds in sequence, auditory closure and figure-to-ground for verbal sounds.

Greater benefits with hearing aids in reverberant and noisy environments.

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REFERENCES

1. Stach BA. Diagnosing central auditory processing disorders in adults. In Roeser RJ, Valente M, Hosford-Dunn H. Audiology – Diagnosis, New York: Thieme, 2000:355-79.
2. Sweetow RW. Training the auditory brain to hear. The Hearing Journal, 2005; 58:10-6.
3. Musiek FE, Baran JA. Amplification and the central auditory nervous system. In Valente M (editor), Hearing Aids: standards, options and limitations. New York: Thieme, 1996:407-37.
4. Baran JA. Auditory processing disorders can negate the benefits of binaural amplification. The Hearing Journal. 2002;55:60.
5. Stach B. Hearing aid amplification and central auditory disorders. In Sandlin RE. (editor) Textbook of hearing aid amplification – 2nd edition, San Diego: Singular Publishing Group. 2000:607-41.
6. Bellis TJ. Assessment and management of central auditory processing disorders in the educational setting: from science to practice. 2nd Edition, San Diego: Singular Publishing Group, 2003.
7. Chermak GD, Musiek FE. Auditory training: principles and approaches for remediation and managing auditory processing disorders. Seminars in Hearing. 2002;23:297-308.
8. Pereira LD, Schochat E. Manual de avaliação do processamento auditivo central, São Paulo, Editora Lovise; 1997.
9. McPherson DL. Late potentials of the auditory system. San Diego, Singular Publishing Group, 1996.
10. Cox RM, Alexander GC. The abbreviated profile of hearing aid benefit. Ear Hear. 1995;16:176-83.
11. Almeida K. Avaliação objetiva e subjetiva do benefício das próteses auditivas em adultos [tese]. São Paulo: Universidade Federal de São Paulo. 1998.
12. Musiek FE. The DIID: a new treatment for APD. The Hearing Journal. 2004; 57:50.
13. Speaks C, Niccum N, Tasell DV. Effects of stimulus material on the dichotic listening performance of patients with sensorineural hearing loss. J Sp Hear Res. 1985;28:16-25.
14. Gatehouse S. The time course and magnitude of perceptual acclimatization to frequency responses: evidence from monaural fitting of hearing aids. J Acoust Soc Am. 1992;92:1258-68.
15. Russo NM, Nicol TG, Zecker SG, Ilayes EA, Kraus N. Auditory training improves neural timing in the human brainstem. Behavioral Brain Research. 2005;156:95-103.
16. Tallal P, Miller SL, Bedi G, Byma G, Xiaoquin W, et al. Language comprehension in language learning impaired children improved with acoustically modified speech. Science. 1996;271:81-4.
17. Merzenich MM, Jenkins WM, Johnston P, Schreiner C, Miller SL, Tallal P. Temporal processing deficits of language-impaired children ameliorated by training. Science, 1996;271:77-80.
18. Musiek FE, Schochat E. Auditory training and central auditory processing disorders – a case study. Seminars in Hearing, 1998;19:357-65.
19. Musiek FE. Auditory Plasticity: what is it and why do clinicians need to know? The Hearing Journal. 2000;55:70.

20. Sweetow RW, Henderson-Sabes J. The need for and development of an adaptative listening and communication enhancement (LACE) program. J. Am. Acad. Audiol. 2006;17:538-58.

21. Chermak GD, Musiek FE, Craig CH. Fundamental concepts and considerations for management. In Chemark GD, Musiek FE, Craig CH, Central auditory processing disorders – new perspectives. San Diego: Singular Publishing Group. 1998:151-83.

22. Baran JA. Management of adolescents and adults with central auditory disorders. In Masters MG, Stecker NA, Katz J. Central auditory processing disorders – mostly management. Boston: Allyn and Bacon, 1998:195-214.

23. Walden TC, Walden BE. Unilateral versus bilateral amplification for adults with impaired hearing. J Am Acad Audiol. 2005;16:574-84.

24. Silverman CA, Emmer MB. Auditory deprivation and recovery in adults with assymetric sensorineural hearing impairment. J Am Acad Audiol. 1993;4:338-46.

25. Mapes FM, Moureau R. The use of decoy sentences to measure auditory training gains. Am Ann Deaf. 1980;125:394-9.

26. Lundborg T. Clinical experiences with communication instruments in adults with sensorineural hearing loss. Audiology. 1980;19:189-201.

27. Tremblay KL, Kraus N. Auditory training induces asymmetrical changes in cortical neural activity. J Sp Lang Hear Res. 2002;45:564-72.

28. Gotteselig JM, Brandeis D, Hofer-Tinguely G, Borbély AA, Achermann P. Human central auditory plasticity associated with tone sequence learning. Learning and memory. 2004;11:162-71.

29. Musiek FE, Shinn J, Hare C. Plasticity, auditory training and auditory processing disorders. Seminars in Hearing, 2002;23:264-75.

30. Hall J. Handbook of auditory evoked responses. Boston:Allyn & Bacon. 1992.

31. Oates PA, Kurtzberg D, Stapells DR. Effects of sensorineural hearing loss on cortical event-related potential and behavioral measures of speech-sound processing. Ear Hear. 2002;23:399-415.

32. Reis ACMB. Estudo do potencial evocado auditivo de longa latência (PEALL) – P300 – em sujeitos com perda auditiva neurossensorial congênita de grau severo e profundo. São Paulo: Universidade Federal de São Paulo.2003.

33. 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, 1998:145-62.

34. Tremblay K, Kraus N, McGee T. The time course of auditory perceptual learning: neurophysiologic changes during speech-sound training. NeuroReport., 1998;9:3557-60.

35. Bucuvic EC. Avaliação subjetiva das dificuldades auditivas e do benefício da amplificação em pacientes novos usuários de aparelho auditivo. Universidade Federal de São Paulo: São Paulo. 2003.

36. Philibert B, Collet L, Vesson J, Veuillet E. The auditory acclimatization effect in sensorineural hearing-impairment listeners: evidence for functional plasticity. Hearing Research, 2005;205:131-42.

37. Jirsa RE. Clinical Efficacy of electrophysiologic measures in APD management programs. Seminars in Hearing.,2002; 23:349-55.

38. Hayes EA, Warrier CM, Nicol TG, Zecker SG, Kraus N. Neural plasticity following auditory training with learning problems. Clin Neurophysiol. 2003;114:673-84.

39. Tremblay KL. Central auditory plasticity: implication for auditory rehabilitation. The Hearing Journal., 2003;56:10-6.

40. Tremblay K, Kraus N, McGee T, Ponton C, Otis B. Central auditory plasticity: changes in N1-P2- complex after speech-sound training. Ear and Hear.2002;22:79-90.

41. Weinstein BE. Outcome measures in rehabilitative audiology. In Alpiner JG, McCarthy PA. Rehabilitative audiology – children and adults. Third ed. Baltimore: Lippincot Williams & Wilkins. 2000:575-594.

42. Chisolm TH, Harvey BA, McArdle R. Short- and long-term outcomes of adults audiological rehabilitation. Ear Hear. 2004;25:464-77.