http://dx.doi.org/10.1590/S2317-64312014000200003

Maintenance of auditory abilities after auditory training

Manutenção das habilidades auditivas pós treinamento auditivo

Renata Filippini[1], Natália Faria Siqueira Brito[2], Ivone Ferreira Neves-Lobo[3], Eliane Schochat[3]

ABSTRACT

Purpose: The aim of the current study was to determine the efficacy of auditory training and to establish the long-term effectiveness of the acquired auditory abilities one, two or three years following the completion of the program. **Methods:** Ten children, who presented abnormal auditory processing ranging in degree from mild-moderate, moderate, to moderate-severe, underwent an 8-week auditory training program. All participants were reassessed immediately after training (POST-1) and one, two or three years after training (POST-2). **Results:** Significant differences were detected in average performance between the assessment made prior to auditory training (PRE) and POST-1 assessment, and between PRE and POST-2 assessments, but no significant differences were found between POST-1 and POST-2 assessments. No correlations were detected between POST-1 and POST-2 time interval, and the difference in performance between these two evaluations. The auditory processing assessments in POST-1 were considered normal, or were mildly altered. Further, 60% of the individuals achieved the same results in POST-2 assessment. **Conclusion:** In the current study, we verified that auditory training is an effective intervention for Auditory Processing Disorders, and that the benefits obtained after training persist even after intervals of one, two or three years following intervention.

Keywords: Auditory perception, Auditory perceptual disorders, Acoustic stimulation, Neuronal plasticity, Learning

RESUMO

Objetivo: Verificar a eficácia do Treinamento Auditivo e a manutenção das habilidades auditivas treinadas após um, dois, ou três anos do seu término, com o intuito de comprovar a eficácia do treino em longo prazo. **Métodos:** Dez crianças com alteração do processamento auditivo - graus variando entre leve a moderado, moderado e moderado a severo - passaram por um programa de treinamento auditivo de oito semanas e foram reavaliadas imediatamente após o treino (PÓS-1) e um, dois, ou três anos depois (PÓS-2). **Resultados:** Foram observadas diferenças significativas no desempenho médio, entre a avaliação pré-treino e as avaliações PÓS-1 e PÓS-2, sem diferenças entre as duas últimas. Não foram observadas correlações entre o intervalo de tempo entre PÓS-1 e PÓS-2 e a diferença no desempenho dessas avaliações. Em PÓS-1, a maioria das avaliações apresentou-se dentro da normalidade, ou com alterações leves do PA, sendo que 60% dos indivíduos mantiveram tais resultados em PÓS-2. **Conclusão:** Verificamos, neste estudo, que o Treinamento Auditivo é eficaz na intervenção dos Transtornos do Processamento Auditivo e que os benefícios obtidos após o treinamento se mantêm, mesmo após um, dois, ou três anos do seu término.

Descritores: Percepção auditiva; Transtornos da percepção auditiva; Estimulação acústica; Plasticidade neuronal; Aprendizagem

This study was conducted within the Department of Physical Therapy, Speech-Language and Audiology Sciences, and Occupational Therapy, Faculty of Medicine, Universidade de São Paulo – USP – São Paulo (SP), Brazil.
(1) Graduate program (Post-doctorate) in Rehabilitation Sciences, Department of Physical Therapy, Speech-Language and Audiology Sciences and Occupational Therapy, Faculty of Medicine, Universidade de São Paulo – USP – São Paulo (SP), Brazil.
(2) Graduate program (Master) in Rehabilitation Sciences, Department of Physical Therapy, Speech-Language and Audiology Sciences and Occupational Therapy, Faculty of Medicine, Universidade de São Paulo – USP – São Paulo (SP), Brazil.
(3) Department of Physical Therapy, Speech-Language and Audiology Sciences and Occupational Therapy, Faculty of Medicine, Universidade de São Paulo – USP – São Paulo (SP), Brazil.
Conflict of interest: No
Authors' contribution: *RF* data collection and analysis, literature review, article writing; *NFSB* methodology design, data collection; *IFNL* literature review, article review; *ES* initial idea proposition, methodology design, study advisory, article review.
Correspondence address: Renata Filippini. R. Cipotânea, 51, Cidade Universitária, São Paulo (SP), Brasil, CEP: 05360-000. E-mail: refilippini@usp.br
Received on: 10/24/2013; **Accepted on:** 2/11/2014

INTRODUCTION

The Auditory Processing Disorder (APD) is related to difficulties in the perceptual processing of the auditory information in the central nervous system and the neurobiological activity that underlies such processing[1,2]. Intervention in cases of APD must be composed of top-down and bottom-up approaches, which consist, of linguistic and cognitive stimulation, and of environmental adaptations, improvement of acoustic signal (e.g.: FM system) and auditory stimulation through Auditory Training (AT)[3,4], respectively.

AT comprises a set of conditions and/or tasks designed to activate the auditory and related systems in such a manner that their neural base and auditory behavior are altered in a positive manner[5]. This alteration is possible because the Auditory Central Nervous System is considered a plastic system, or in other words, a system capable of promoting changes to the nerve cells according to environmental influences[6].

Several studies have been demonstrated the benefits of AT in children with APD using behavioral and electrophysiological assessments[4,7-14], which suggests that the efficacy of the perceptual auditory system may be improved through training.

The beneficial effects of AT have been called "perceptual learning," and some authors suggested that this learning take place in two stages. The first stage is a brief phase that occurs during the training session, and might reflect the learning of the stimulus and the concept, such as learning the procedures and tasks. The second stage involves slow development, occurs during consolidation, and might take from six or eight hours to weeks, most likely reflecting the changes in long-term memory[15-17].

The consolidation and maintenance of the benefits obtained in the auditory abilities after AT has been a concern among researchers and clinicians, because, generally, assessments are conducted immediately following the completion of the final training session, and no long-term patient follow-up is performed. In fact, only a limited number of studies have attempted to verify the long-term maintenance of the effects of AT on auditory abilities[18-20], and the maintenance of results has only been verified for a few weeks or months after AT.

The aim of the current study was to verify the effectiveness of AT, as well as to prove the long-term efficacy of this program for the maintenance of the trained auditory abilities, through auditory processing (AP) behavioral reevaluation one, two or three years after the completion of training.

METHODS

This study was conducted in the Auditory Processing Laboratory within the Department of Physical Therapy, Speech-Language and Audiology Sciences and Occupational Therapy, at the Universidade de São Paulo, Faculty of Medicine. The study received full approval from the Faculty of Medicine Ethics in Research Committee, and was conducted under the research protocol number 0117/08.

The ten subjects who participated in this study were aged 7 to 14 years (9.6±2.9), during the first assessment, and 8 to 17 years (12±2,7) in the last assessment. All study participants went through an AT program proposed in previous studies and validated in Brazil[7,21,22] that consisted of a weekly 50-min acoustic booth session designed to stimulate the abnormal auditory abilities, with duration of eight weeks. At the end of the AT program, the patient was reassessed using the same test battery employed in the initial assessment, to verify improvements in the trained auditory abilities.

All subjects underwent AP behavioral assessment before AT (PRE), right after AT (POST-1) and one, two or three years after AT (POST-2). At the time of the assessments all subjects presented hearing thresholds under 20 dBHL (250-8000 Hz), and tympanometry type A with the presence of acoustic reflex for both 1000 and 2000 Hz. All parents or guardians signed the informed consent formulary.

The tests used in the current study were chosen according to the age, complaint and motor/linguistic conditions of each individual participant. The repeat assessments consisted of the same tests applied during the initial assessment (Chart 1).

Chart 1. Tests applied in the assessment and reassessment, according to the evaluated auditory ability

Evaluated auditory skill	Test	n*
Sound localization	Sound localization test (SL)	9
Auditory memory	Sequence memory to verbal sounds (SMV)	9
	Sequence memory to non-verbal sounds (SMNV)	9
Auditory closure	Speech in noise test (SN)	9
Auditory figure-ground	Pediatric Speech Intelligibility (PSI)	9
	Dichotic Digits (DD)	4
	Staggered Spondaic Word (SSW)	6
	Nonverbal dichotic test (NVD)	7
Temporal sequencing	Pitch Pattern Sequencing (PPS)	8

*number of subjects evaluated in each test

The criteria for normality, and assessment materials used in the current study, are widely used in clinical practice[23-25]. The performance on each test and the number of abnormal responses were used to determine the alteration degree of the AP assessment, and the same criterion was maintained throughout all assessments.

The performances of each test at PRE, POST-1 and POST-2 assessments, as well as the degree of AP alteration of each assessment, were compared. The correlation between AP alteration and the different time intervals between POST-1 and

Table 1. Mean performance (M) and standard deviation (SD) for each test (%), according to the evaluation

Evaluation	SL		SMV		SMNV		PSI		SN		PPS		NVD		SSW/DD	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
PRE	93.3	14.1	77.8	28.9	33.3	23.6	71.7	16.2	71.2	17.6	46.0	13.6	59.5	26.7	65.0	19.7
POST-1	97.8	6.7	77.8	28.8	51.9	24.2	75.0	15.8	83.4	11.9	85.0	7.9	86.9	17.2	78.0	17.9
POST-2	100	0	81.5	24.2	55.6	40.8	79.4	15.1	82.2	7.0	71.0	12.9	88.7	16.9	79.5	20.4

Note: SL = sound localization; SMV = sequence memory to verbal sounds; SMNV = sequence memory to non-verbal sounds; PSI = pediatric speech intelligibility test; SN = speech in noise; PPS = pitch pattern sequencing; NVD = nonverbal dichotic test, SSW/TDD = staggered spondaic word/dichotic digits

POST-2 was also verified. Pearson Correlation, a Student's t-Test, and analysis of variance (ANOVA), were used for data analysis, all with 5% level of significance.

RESULTS

No differences were detected between right and left ears in any of the tests that evaluated the ears individually ($p>0.05$ in all comparisons). Thus, we choose to combine the results of both ears, so that the analysis would yield greater statistical power.

An increase in the average number of correct responses was observed between PRE and POST-1 assessments, and the observed increase was maintained at POST-2 assessment (Table 1).

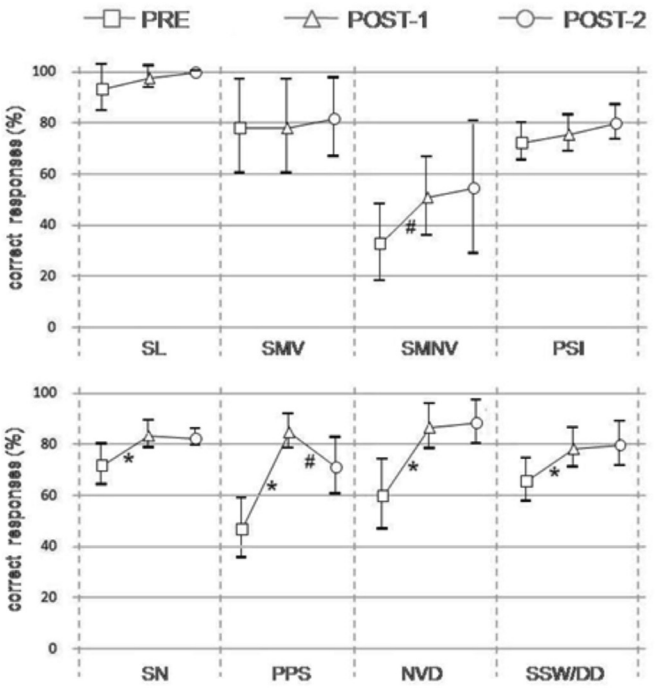
Differences between PRE, POST-1 and POST-2 were verified for the following tests: SN, PPS, NVD, and SSW/DD. The differences observed were due to distinctions between performances in PRE and POST-1 assessments (SN: $p=0.020$; PPS: $p<0.001$; NVD: $p=0.003$; SSW/DD: $p=0.035$) and PRE and POST-2 assessments (SN: $p=0.019$; PPS: $p=0.017$; NVD: $p=0.001$; SSW/DD: $p=0.027$). No differences were observed in any of the applied tests between POST-1 and POST-2 assessments (Figure 1).

Among the ten participants, the time interval between the POST-1 and POST-2 assessments was three years in five participants, two years in three participants, and one year in two participants. No correlations were observed for any applied tests between the POST-1 and POST-2 time intervals, and the performance differences between both assessments.

Regarding the degree of alteration of AP assessment, at the initial assessment (PRE), the participants of the study presented mild to moderate alteration (10%, n=1), moderate alteration (70%, n=7), or moderate to severe alteration (20%, n=2). Immediately following AT (POST-1) all individuals demonstrated an improvement in the AP assessment, with the majority of the performances falling within normal range (40%, n=4) or with only mild alterations (40%, n=4). At POST-2 assessment, 60% of the participants returned the same results they had obtained in POST-1. Among the rest of the participants, one exhibited improvement and three had results that were lower than POST-1 assessment (Figure 2).

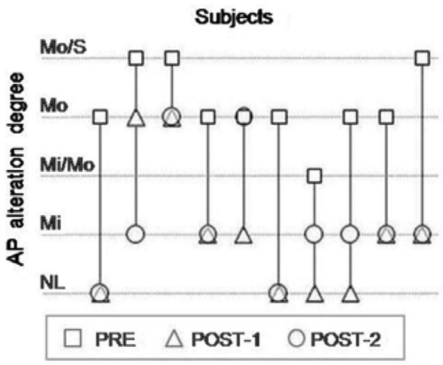
DISCUSSION

In the current study, we observed improvement in AP after



Note: (*) $p\leq0,05$; (#) $0,09<p<0,05$; SL = sound localization; SMV = sequence memory to verbal sounds; SMNV = sequence memory to non-verbal sounds; PSI = pediatric speech intelligibility test; SN = speech in noise; PPS = pitch pattern sequencing; NVD = nonverbal dichotic test, SSW/TDD = staggered spondaic word/dichotic digits

Figure 1. Error Bars and mean percentage of correct responses to each assessment, according to the applied test



Note: Mo/S = Moderate to severe; Mo = Moderate; Mi/Mo = Mild to Moderate; Mi = Mild; NL = Normal

Figure 2. Distribution of AP alteration degree by subjects, in all assessments

training, as well as the maintenance of such improvement, even as long as three years after training. Other researchers[10,11] reported similar results, with approximately 70% of the individuals assessed performing normally after AT. Moreover, prior studies also demonstrated the efficacy of AT in children with APD[4,7-9,12,13].

The tests used in this study were considered stable by test-retest studies that involved individuals with typical development[26]. Consequently, changes in performance suggest modifications in the auditory system and its functions as consequence of cellular reorganization promoted by lesion-induced compensation, stimulation-induced learning, or natural system maturation[6].

We believe that in the current study, the changes observed after the completion of the AT program took place because of auditory learning induced by training. The basis of our conviction was the fact that the interval between PRE and POST-1 assessments was only eight weeks, which is not considered enough time to justify changes based only on the maturation of subjects within the age range of those included in the study.

The observation that the maintenance of acquired behavioral improvements was relatively constant for a period of three years following AT is of extreme importance to the field, considering the limited number of previous studies that investigated the maintenance of auditory stimulation benefits months or years after the end of an AT program.

In another study[18], the maintenance of acquired improvements up to six months after AT was reported for a high proportion of the subjects (85%). According to the authors of the prior study, non-auditory factors, such as emotional, cognitive, memory or attention disorders, might have interfered with the assessments of children who did not maintain their improved performances.

While analyzing the responses to language and word discrimination tests given by typical developing school children after auditory discrimination training, a different study[19] resulted in reports of observed improvements to both phonological and auditory abilities, with maintenance of these improvements five or six weeks after the end of AT.

On the other hand, the results of a study aimed at verifying the auditory and cognitive benefits of an AT program in an adult with a Traumatic Brain Injury[20], indicated maintenance of the improved behavioral auditory responses four months after training, but not of the electrophysiological or cognitive tests responses. The authors argued that perhaps the patient required additional AT sessions to reach consolidation of the auditory learning in a manner that allowed for the maintenance of acquired improvements in all assessment levels.

In the current study, three individuals reverted to unsatisfactory results at POST-2 assessment. One of the individuals was a child diagnosed with hyperactivity and another was undergoing psychological assessment due to behavioral problems and difficulties socializing. Considering that both AP assessment and learning process may be influenced or depend upon non-auditory factors[14,17], we believe that for these individuals, such factors, including attention problems and lack of motivation, may have influenced their performance during POST-2 assessment. Another hypothesis is that once these patients demonstrated clear involvement of other non-auditory alterations, they might have failed at the learning consolidation process, and, would perhaps have benefitted from additional training sessions, to achieve consolidation of the AT-induced cellular reorganization.

The fact that we did not observe a correlation between the POST-1 and POST-2 time interval, and the difference in performance between these assessments suggested that after consolidation, the changes obtained during AT were maintained for at least three years, the longest time interval observed in this study.

On the basis of the current study results as well as the literature analyzed we can suggest auditory training induced positive behavioral changes, and that these modifications could last for a long term.

CONCLUSION

The current study verified, through behavioral AP assessments, that auditory training is an efficient intervention for APD and that the benefits obtained after training are maintained even after one, two or three years.

REFERENCES

1. American Speech-Language-Hearing Association. Auditory processing disorders: the role of audiologist [internet]; 2005 [Acesso em: 22 jan 2013]. Disponível em: http://www.asha.org/policy/PS2005-00114.htm

2. American Academy of Audiology. American Academy of Audiology clinical practice guidelines: diagnosis, treatment and management of children and adults with central auditory processing disorder [internet]; 2010 [Acesso em: 22 jan 2013]. Disponível em: http://www.audiology.org/resources/documentlibrary/Pages/CentralAuditoryProcessingDisorder.aspx

3. Chermak GD, Musiek FE. Auditory training: principles and approaches for remediating and managing auditory processing disorders. Semin Hear. 2002;23(4):297-308. http://dx.doi.org/10.1055/s-2002-35878

4. Sharma M, Purdy SC, Kelly AS. A randomized control trial of interventions in school-aged children with auditory processing disorders. Int J Audiol. 2012;51(7):506-18. http://dx.doi.org/10.3109/14992027.2012.670272

5. Musiek FE, Chermak GD, Weihing J. Auditory training. In: Chermak GD, Musiek FE. Handbook of (central) auditory processing disorder. San Diego: Plural; 2007. Volume 2, p.77-106.

6. Musiek FE, Shinn JMS, Hare CMA. Plasticity, auditory training and auditory processing disorders. Semin Hear. 2002;23(4):263-75.

7. Musiek FE, Schochat E. Auditory training and central auditory processing disorders: a case study. Semin Hear. 1998;19(4):357-66.
8. Putter-Katz H, Said LA-B, Feldman I, Miran D, Kushnir D, Muchnik C, et al. Treatment and evaluation indices of auditory processing disorder. Seminar Hear. 2002;23(4):357-64.
9. Kozlowski L, Wiemes GMR, Magni C, Silva ALG. A efetividade do treinamento auditivo na desordem do processamento auditivo central: estudo de caso. Rev Bras Otorrinolaringol. 2004;70(3):427-32. http://dx.doi.org/10.1590/S0034-72992004000300023
10. Zalcman TE, Schochat E. A eficácia do treinamento auditivo formal em indivíduos com transtorno de processamento auditivo. Rev Soc Bras Fonoaudiol. 2007;12(4):310-4. http://dx.doi.org/10.1590/S1516-80342007000400010
11. Alonso R, Schochat E. A eficácia do treinamento auditivo formal em crianças com transtorno de processameento auditivo (central): avaliação comportamental e eletrofisiológica. Braz J Otorhinolaryngol. 2009;75(5):726-32. http://dx.doi.org/10.1590/S1808-86942009000500019
12. Filippini R, Befi-Lopes DM, Schochat E. Efficacy of auditory training using the auditory brainstem response to complex sounds: auditory processing disorder and specific language impairment. Folia Phoniatr Logop. 2012;64(5):217-26. http://dx.doi.org/10.1159/000342139
13. Murphy CFB, Schochat E. Effects of different types of auditory temporal training on language skills: a systematic review. Clinics (São Paulo). 2013;68(10):1364-70. http://dx.doi.org/10.6061/clinics/2013(10)12
14. Wilson WJ, Arnott W, Henning C. A systematic review of electrophysiological outcomes following auditory training in school-age children with auditory processing deficits. Int J Audiol. 2013;52(11):721-30. http://dx.doi.org/10.3109/14992027.2013.809484
15. Bratzke D, Schröter H, Ulrich R. The role of consolidation for perceptual learning in temporal discrimination within and across modalities. Acta Psychol. 2014;147:75-9. http://dx.doi.org/10.1016/j.actpsy.2013.06.018
16. Ortiz JA, Wright BA. Contributions of procedure and stimulus learning to early, rapid perceptual improvements. J Exp Psychol Hum Percept Perform. 2009;35(1):188-94. http://dx.doi.org/10.1037/a0013161
17. Atienza M, Cantero JL, Dominguez-Marin E. The time course of neural changes underlying auditory perceptual learning. Learn Mem. 2002;9(3):138-50. http://dx.doi.org/10.1101/lm.46502
18. Schochat E, Carvalho LZ, Megale RL. Treinamento auditivo: avaliação da manutenção das habilidades. Pró-Fono Rev Atual Cient. 2002;14(1):93-8.
19. Moore DR, Rosenberg JF, Coleman JS. Discrimination training of phonemic constrasts enhances phonological processing in mainstream school children. Brain Lang. 2005;94(1):72-85.
20. Murphy CFB, Filippini R, Palma D, Zalcman TE, Lima JP, Schochat E. Auditory training and cognitive functioning in adult with traumatic brain injury. Clinics (São Paulo). 2011;66(4):713-5. http://dx.doi.org/10.1590/S1807-59322011000400030
21. Chermak GD, Musiek FE. Managing central auditory processing disorders in children and youth. Am J Audiol. 1992;1(3):61-5. http://dx.doi.org/10.1044/1059-0889.0103.61
22. Chermak GD, Musiek FE. Three commonly asked questions about central auditory processing disorders management. Am J Audiol. 1995;4(1):15-8. http://dx.doi.org/10.1044/1059-0889.0401.15
23. Pereira LD, Schochat E. Processamento auditivo central: manual de avaliação. São Paulo: Lovise; 1997.
24. Pereira LD, Schochat E. Testes auditivos comportamentais para avaliação do processamento auditivo central. São Paulo: Pró-Fono; 2011.
25. Auditec. Evaluation manual of pitch pattern sequence and duration pattern sequence. Saint Louis; Auditec; 1997.
26. Frascá MFSS, Neves-Lobo IF, Schochat E. Processamento auditivo em teste e reteste: confiabilidade da avaliação. Rev Soc Bras Fonoaudiol. 2011;16(1):42-8.