

RESEARCH ARTICLE

Developing a temporal processing-based auditory training program for the senior users of hearing aids: a home PC-based program

Karim Sattari^{1,2}, Nariman Rahbar^{1,2*}, Mohsen Ahadi^{1,2}, Hamid Haghani³

¹- Department of Audiology, School of Rehabilitation Sciences, Iran University of Medical Sciences, Tehran, Iran

²- Rehabilitation Research Center, Iran University of Medical Sciences, Tehran, Iran

³- Department of Biostatistics, School of Management and Information Technology, Iran University of Medical Sciences, Tehran, Iran

Received: 16 Oct 2020, Revised: 2 Dec 2020, Accepted: 23 Dec 2020, Published: 15 Jan 2021

Abstract

Background and Aim: One of the consequences of aging is temporal processing impairment and reduced neural synchronization, which reduces speech comprehension in challenging situations such as noisy and reflective environments. This study aimed to develop a novel temporal processing-based auditory training program for the senior users of hearing aids.

Methods: The program was designed based on different aspects of temporal processing and consists of multiple duty including: 1) detect the number of stimuli, 2) detect the pitch of the stimuli, 3) detect the duration pattern, 4) detect the number of nonsense speech stimuli in noise, and 5) detect the gap in noise. The program consists of 36 sessions (1800 exercises) and one or more features of temporal processing are challenged in all sections.

Results: Content validity ratio, content validity index and impact score were used for validation. The results showed acceptable validity.

Conclusion: Since training exercises can improve the physiological representation of sounds

by changing hearing maps and temporal decoding, and these changes lead to improved perception, therefore, the auditory rehabilitation program for the seniors with emphasis on the temporal features of speech, was designed and developed. So it is hoped that with the implementation of the rehabilitation program in the seniors with hearing loss, the effects of age related hearing loss, including depression and social isolation, will be reduced to some extent.

Keywords: Aging; presbycusis; temporal processing; auditory training; hearing loss

Citation: Sattari K, Rahbar N, Ahadi M, Haghani H. Developing a temporal processing-based auditory training program for the senior users of hearing aids: a home PC-based program. *Aud Vestib Res.* 2021;30(1):42-9.

Introduction

Age-related hearing loss or presbycusis is one of the most common health conditions involving the senior citizen. Presbycusis is the second most common health condition in people aged above 65 after arthritis. Such complications are even more prevalent in the ones aged above 75 years [1]. The two main clinical signs of presbycusis are shifts in hearing thresholds and decreased

* **Corresponding author:** Department of Audiology, School of Rehabilitation Sciences, Iran University of Medical Sciences, Shahid Shahnazari St., Madar Square, Mirdamad Blvd., Tehran, 15459-13487, Iran. Tel: 009821-22228051, E-mail: rahbar.n@iums.ac.ir

speech comprehension [2].

Neurophysiological researches have shown that (central) auditory processing is also damaged by hearing impairment and aging, and it is specified that temporal processing skills are most affected by age [3]. Most of the elderly people with hearing loss can hear and understand speech more accurately when others speak slowly but have problems in understanding quick speech. This condition is attributed to the slower processing of the auditory system due to aging [4]. There are many potential biological causes that may slow down aging responses, such as decreased myelin integrity [5], prolonged nerve recovery [6], decreased brain connections [7], decreased neural synchrony [8], reduced levels of inhibitory neurotransmitters such as GABA in cochlear nucleus (CN), inferior colliculus (IC) and auditory cortex [9], and reduced levels of excitatory neurotransmitters such as acetylcholine [9]. Most audiologists amplify sounds using hearing aids for the rehabilitation of people with hearing impairments. This is the first-line solution, but successful rehabilitation depends on the ability of the central auditory system to represent and integrate the spectral and temporal information contained in the speech signal heard through the amplifier. The extent to which individuals benefit from wearing a hearing aid depends in part on the ability of his/her central auditory system to adapt to the signals corrected by the prosthesis. People who do not benefit much from hearing aids may have difficulty in the plasticity of the auditory system; those who do not have a good perception of speech have difficulty learning in connecting new neural patterns with their previous memory of sounds and have slower learning [10]. The mentioned topics provide a platform for the use of auditory training exercises activities (a type of auditory stimulation).

Since exercise-related physiological changes can lead to improved perception, the physiological representation of sounds can be modified using training exercises. Animal studies have shown that training leads to changes in auditory mapping and temporal decoding. Auditory rehabilitation exercises are designed to improve the individual's ability to understand auditory events

through repeated listening exercises [11].

There are three types of neural plasticity that including maturational, compensatory, and learning-related, which is achieved through practice and training. Although all the three types of plasticity affect auditory training, success in auditory training and other behavioral and rehabilitation efforts significantly depends on learning-related plasticity [12].

Training-related physiological changes can lead to multiple different processes, as a) responsive neurons in the sensory field increases b) neuronal synchrony increases c) With training, the activity among the neurons becomes dissimilar (neuronal de-correlative process), meaning that each neuron has a distinct and unique function [13].

According to the above therefore, auditory-based rehabilitation training can partly restore age-related damages in temporal processing in the brain, and this plasticity, in turn, leads to the improvement of perceptual and cognitive skills. The "plasticity" phenomenon reflects the efficacy of auditory rehabilitation on improving the speech perception skills of the senior citizens. So, various auditory rehabilitation procedures have been introduced and multiple software programs for auditory training were developed. Including Fast-forward (2001), Earobics (1999), Learning Fundamentals, Otto's World of Sounds, Conversation Made Easy, LiSN and Learn and dichotic interaural intensity difference [14,15]. In Iran, we need to design and develop such methods based on the senior citizen's needs. In existing rehabilitation programs for hearing-impaired senior citizen, temporal processing is not considered. So, an elderly auditory training program was developed with an emphasis on various aspects of temporal processing as follows: temporal ordering (sequencing) that is related to hearing and recognizing sequences of two or more auditory stimuli. This listening skill, in addition to stimulating the function of the left and right hemispheres as well as inter-hemisphere pathways, also involves multiple perceptual and cognitive processes, since the patient should first distinguish and differentiate two or more sounds in the order created, and then name the stimulus pattern [16]. Temporal asynchrony (discrimination) that

is related to hearing and temporal differentiation of short and long stimuli. In other words, the temporal alignment of the two stimuli is different, and the listener should be able to differentiate between these two stimuli [17]. Temporal integration (summation), including longer stimuli; by reducing the stimulus duration, especially to less than 200 ms, distinguishing becomes more difficult. Therefore, decreasing the duration of a tone or noise burst increases the threshold [18]. Temporal masking, including listening to target stimuli in the presence of noise with a varying signal to noise ratio (SNR) in a certain period. It is the interaction between two sounds created simultaneously, and this effect is systematically increased by reducing the interval between the stimulus and the masker [19]. Temporal resolution (gap detection), including detection of the gap between two stimuli; studies show that for both adults and children aged seven years and over, the approximate threshold is approximately ≥ 8 ms [20].

One of the remarkable features of this program is that it does not require special tools and can be easily run at home by a laptop or desktop by the user. PC-based programs enable us to precisely control stimuli and their equipment is available [21].

Methods

The design and development of the introduced program was part of a large, two-step research project. In the first phase, a temporal processing-based auditory training program was designed and developed, and in the second phase, the efficacy of the rehabilitation program on the auditory skills of the 18 senior citizen was examined in another study. Study subjects had 60–75 years-old with bilateral mild to moderate sensorineural hearing loss and experience of using binaural hearing aids for more than three months.

Designating and developing the program

The auditory training program was designed based on the theoretical framework of temporal processing to be applicable in both formal and informal rehabilitation sessions by the user himself at home. Since this program is innovative

and for the first time in Iran that this aspect has been considered in the rehabilitation of the elderly, so validation processes were performed for it.

In order to ensure face validity, the program was performed for six seniors at the Persiatone Audiology Center, who were then asked to determine if the program could be considered a rehabilitation program and implemented over a long period of time. This was a written question and people had to choose one of the options (yes, completely) (partly) (not at all). The impact score of all items was 4 (acceptable value was 1.5), so the program had appropriate face validity.

The program was presented to 10 academic experts to determine its content validity ratio (CVR) and content validity index (CVI). The relevant questions were: 1) detect the number of stimuli: (wholly suitable/suitable/not suitable/suggestions), 2) detect the pitch of the stimuli: (wholly suitable/suitable/not suitable/suggestions), 3) detect the duration pattern: (wholly suitable/suitable/not suitable/suggestions), 4) detect the number of nonsense speech stimuli in noise: (wholly suitable/suitable/not suitable/suggestions), and 5) detect the gap in noise: (wholly suitable/suitable/not suitable/suggestions).

The program was thoroughly reviewed by an expert panel, and the existing bugs were fixed. The experts were audiologist and academic members of Iran University of Medical Sciences, Tehran University of Medical Sciences, and Shahid Beheshti University of Medical Sciences. The CVR of the prepared questions was 1, Indicated that questions were prepared properly. CVR values range from -1 (perfect disagreement) to $+1$ (perfect agreement). Individual item CVI and overall scale CVI were then calculated that in all items were 1. The program was completed and reconstructed, and then in the next phase was provided to the research subjects as software for home application (a home PC-based program).

Program details, implementation and user requirements

The details of the program have been published

Table 1. Details of session 1 (easy stage) of the introduced rehabilitation program

Stage	Level	Task	Exercise no.	1	2	3	4	5	Stimulus characteristics
Easy (1)	Level 1	Task 1	1.1.1	500	500 & 4000	N & N	500 & 500 & 500	500 & 1000 & 2000	F (Hz)/N = WN D = 250 ms Gap = 250 ms
		Task 2	1.1.2	250 & 4000	250 & 250	4000 & 4000 & 250	250 & 250 & 4000	250 & 250 & 250	F (Hz) D = 1000 ms Gap = 1 s
		Task 3	1.1.3	500 LLL	500 SSS	500 LLS	500 SSL	500 LSL	F = 500 Hz L = 600 ms S = 300 ms Gap = 250 ms
		Task 4	1.1.4	da	da/ta	ta/ba	da/ta/ba	ta/ba/da	D = 6 s/M SNR = 12 dB
		Task 5	1.1.5	0	1 (42)	2 (42 - 41)	3 (42 - 41 - 40)	2 (42 - 40)	N = 6 s Gap = ms

Task 1: detecting the number of stimuli, Task 2: detecting the pitch of the stimuli, Task 3: detecting the duration pattern, Task 4: detecting the number of nonsense speech stimuli in noise, task 5: detecting the gap in noise
s; second, F; frequency, D; duration, L; long, S; short, N; noise, WN; white noise, M; male, SNR; signal to noise ratio

previously in a study protocol [22]. The program should be used when the user is alert and free of distractions. The program consists of easy, medium, and hard stages, each with 12 levels. At each level, five temporal processing items are considered with five exercises. Since each exercise should be repeated twice, each session consists of 50 exercises, which are performed by the user according to the description of each item. Since the program consists of 36 sessions, the auditory training program comprises 1800 exercises, all of which were developed by the researcher with Adobe Audition 3.0 program and were provided to the programming engineer for use in making and designing rehabilitation software. Each stage continues for one month and is performed by the user for three sessions per week (35–45 minutes per session). One or more aspects of temporal processing are challenged in all items. In the first sessions, the user's task is simple, while in the subsequent sessions, it becomes more difficult, requiring greater precision. Indeed, the program is based on the repetition of exercises. Regarding the designed program, only the first session was active and accessible, and the next sessions were inactive. The users should gain at least 80% of

the score of each session to enter the next level; otherwise, they should repeat the session to gain the required score. The stimuli were randomly presented at all stages and steps of the program. In other words, in case of failure to gain the required score to enter the next level, the stimuli are not predictable in repetitions. The program must be implemented at most comfortable level for users with hearing aids in the free field. To familiarize users with the rehabilitation program and ensure the proper implementation of the program, the first three sessions (first week) are held in the audiology clinic and in the presence of an audiologist, and subsequent sessions will be done at home according to the program protocol and training of each part of the program.

The details of sessions 1 (easy stage), 18 (medium stage), and 36 (hard stage) of the introduced rehabilitation program are shown as a sample for comparison in tables 1, 2 and 3.

Discussion

It is evident that the ability of temporal processing of the auditory system, including the gap detection, decreases with age. It changes at the suprathreshold levels and decreases with age

Table 2. Details of session 18 (medium stage) of the introduced rehabilitation program

Stage	Level	Task	Exercise no.	1	2	3	4	5	Stimulus characteristics
Medium (2)	Level 18	Task 1	2.6.1	2000	2000 & 2000	N & 2000	2000 & 2000 & 2000	500 & N & N	F (Hz)/N = WN D = 165 ms Gap = 165 ms
		Task 2	2.6.2	500 & 2000	2000 & 2000	500 & 500 & 2000	2000 & 2000 & 500	2000 & 2000 & 2000	F (Hz) D = 575 ms Gap = 1 s
		Task 3	2.6.3	2000 LLL	2000 SSS	2000 LLS	2000 SSL	2000 SLS	F = 2000 Hz L = 500 ms S = 250 ms Gap = 200 ms
		Task 4	2.6.4	ba	ba/da	da/ta	ba/da/ta	da/ta/ba	D = 6 s/Fe SNR = 4 dB
		Task 5	2.6.5	0	1 (25)	2 (25 - 24)	3 (25 - 24 - 23)	2 (25 - 23)	N = 6 s Gap = ms

Task 1: detecting the number of stimuli, Task 2: detecting the pitch of the stimuli, Task 3: detecting the duration pattern, Task 4: detecting the number of nonsense speech stimuli in noise, task 5: detecting the gap in noise
s; second, F; frequency, D; duration, L; long, S; short, N; noise, WN; white noise, Fe; female, SNR; signal to noise ratio

[23,24]. Today, reforming the auditory system using training exercises to strengthen comprehension is one of the most important research trends. There are several evidences that humans (with or without hearing loss) can improve their ability to perceive temporal and spectral aspects of acoustic stimuli through auditory rehabilitation exercises [9,11].

Studies show that sensory deprivation impairs the function of many auditory sensory neurons in the brainstem. Based on the growing evidence of neuroscience in neural plasticity, and the fact that the central auditory nervous system (CANS) of human has plasticity and flexibility, attentions are dragged to the central nervous system (CNS) and the development of rehabilitation methods to treat such impairments. The auditory neuroplasticity has a key impress in the effect of auditory training on the CANS [12].

The approach to auditory training is observed in adults and the senior citizens [25,26]. Several programs are introduced thus far to increase auditory processing skills. The Katz auditory rehabilitation program [27] was developed based on a phonemic synthesis combination, especially for patients with auditory processing disorders.

Other programs, with an emphasis on temporal aspects of speech, were presented to improve the clarity of the speech signal when the intensity of the transient features of speech increases (formant transient). Thus, numerous rehabilitation programs with different goals were introduced one after the other [12]. Such programs were presented formally or informally. Since it is difficult to attend follow-ups or pay daily visits to receive treatment in some remote areas, the programs are also designed informally to be applicable at home. At present, the design and development of auditory rehabilitation programs, especially with an emphasis on processing skills in the CNS, are of interest in many audiology research centers. Informal auditory rehabilitation programs are now developed in a variety of forms and include software programs run by laptops, CDs, videotapes, and virtual programs received, implemented, and monitored via the Internet.

The goals of auditory rehabilitation in the senior citizen are: to establish social interactions, reduce communication limitations, increase participation and encourage patients to improve their performance, create a sense of independence,

Table 3. Details of session 36 (hard stage) of the introduced rehabilitation program

Stage	Level	Task	Exercise no.	1	2	3	4	5	Stimulus characteristics
Hard (3)	Level 36	Task 1	3.12.1	500	1000 & 2000	N & N	N & 500 & 500	500 & 1000 & N	F (Hz)/N = WN D = 75 ms Gap = 75 ms
		Task 2	3.12.2	2000 & 4000	4000 & 4000	2000 & 4000 & 2000	4000 & 2000 & 4000	2000 & 2000 & 2000	F (Hz) D = 125 ms Gap = 1 s
		Task 3	3.12.3	2000 LLL	2000 SSS	2000 LLS	2000 SSL	2000 SLS	F = 2000 Hz L = 400 ms S = 200 ms Gap = 100 ms
		Task 4	3.12.4		ba	da/ta	ba/da/ta	da/ta/ba	D = 6 s/Fe SNR = -5 dB
		Task 5	3.12.5	0	1 (8.5)	2 (8.5 - 8)	3 (8.5 - 8 - 7.5)	2 (8.5 - 7.5)	N = 6 s Gap = ms

Task 1: detecting the number of stimuli, Task 2: detecting the pitch of the stimuli, Task 3: detecting the duration pattern, Task 4: detecting the number of nonsense speech stimuli in noise, task 5: detecting the gap in noise
s; second, F; frequency, D; duration, L; long, S; short, N; noise, WN; white noise, Fe; female, SNR; signal to noise ratio

increase the quality of life, and develop a sense of happiness [26]. Based on this change in attitude, several auditory training programs are introduced for different age groups. These programs can generally be categorized into two groups: programs designed for the senior citizen using hearing aids and programs designed to compensate for auditory processing disorders in the senior citizen [28-31]. One of the important issues in maintaining the health and quality of life of the senior citizens is to maintain their independence in daily life activities and to provide appropriate situations for them to have an active and independent life [32,33]. Therefore, it is expected that the designed auditory rehabilitation programs can improve the communication performance of the elderly who, despite having hearing aids, are dissatisfied with the problem of speech comprehension in noisy environments. For this purpose, a senior citizen auditory rehabilitation program was developed with an emphasis on the temporal aspects of speech.

The minimal system requirements

The program can be done on a home computer and the minimum system requirements needed to run the software is:

- Computer with a minimum 4 GB RAM
- CD-ROM drive
- VGA capable of 1024*768 screen resolution
- Operating system – windows XP, windows Vista, windows 7, windows 8 or windows 10
- High quality speakers
- Any CPU (Intel i3, i5, i7)

Software availability

Source code available from:
<https://github.com/karimsattari/source-code-of-auditory-training/tree/V2.0.0>

Acknowledgments

This study was registered in Iranian Registry of Clinical Trials ([IRCT20190921044838N1](https://www.irct.ir/IRCT20190921044838N1)) on December 25, 2019 and has been approved by the Medical Ethics Committee (IR.IUMS.REC.1397.652). This paper is part of a Ph.D. dissertation approved by Iran University of Medical Sciences.

Conflict of interest

No conflict of interest were disclosed.

References

1. Fato M. Clinical approach to the geriatric patient. In:

- Calhoun KH, Eibling DE, editors. Geriatric otolaryngology. 1st ed. New York, NY: Taylor & Francis Group; 2006. p. 1-16.
2. Divenyi PL, Stark PB, Haupt KM. Decline of speech understanding and auditory thresholds in the elderly. *J Acoust Soc Am.* 2005;118(2):1089-100. doi: [10.1121/1.1953207](https://doi.org/10.1121/1.1953207)
 3. Fitzgibbons PJ, Gordon-Salant S. Age-related differences in discrimination of temporal intervals in accented tone sequences. *Hear Res.* 2010;264(1-2):41-7. doi: [10.1016/j.heares.2009.11.008](https://doi.org/10.1016/j.heares.2009.11.008)
 4. Huang Q, Tang J. Age-related hearing loss or presbycusis. *Eur Arch Otorhinolaryngol.* 2010;267(8):1179-91. doi: [10.1007/s00405-010-1270-7](https://doi.org/10.1007/s00405-010-1270-7)
 5. Lu PH, Lee GJ, Raven EP, Tingus K, Khoo T, Thompson PM, et al. Age-related slowing in cognitive processing speed is associated with myelin integrity in a very healthy elderly sample. *J Clin Exp Neuropsychol.* 2011;33(10):1059-68. doi: [10.1080/13803395.2011.595397](https://doi.org/10.1080/13803395.2011.595397)
 6. Parthasarathy A, Bartlett EL. Age-related auditory deficits in temporal processing in F-344 rats. *Neuroscience.* 2011;192:619-30. doi: [10.1016/j.neuroscience.2011.06.042](https://doi.org/10.1016/j.neuroscience.2011.06.042)
 7. Forstmann BU, Tittgemeyer M, Wagenmakers EJ, Derrfuss J, Imperati D, Brown S. The speed-accuracy tradeoff in the elderly brain: a structural model-based approach. *J Neurosci.* 2011;31(47):17242-9. doi: [10.1523/JNEUROSCI.0309-11.2011](https://doi.org/10.1523/JNEUROSCI.0309-11.2011)
 8. Schneider BA, Pichora-Fuller MK. Age-related changes in temporal processing: Implications for speech perception. *Semin Hear.* 2001; 22(3):227-40. doi: [10.1055/s-2001-15628](https://doi.org/10.1055/s-2001-15628)
 9. Anderson S, White-Schwoch T, Parbery-Clark A, Kraus N. Reversal of age-related neural timing delays with training. *Proc Natl Acad Sci U S A.* 2013;110(11):4357-62. doi: [10.1073/pnas.1213555110](https://doi.org/10.1073/pnas.1213555110)
 10. Tremblay KL. Hearing aids and the brain: What's the connection? *Hear J.* 2006;59(8):10. doi: [10.1097/01.HJ.0000286369.99925.79](https://doi.org/10.1097/01.HJ.0000286369.99925.79)
 11. Alain C, Snyder JS, He Y, Reinke KS. Changes in auditory cortex parallel rapid perceptual learning. *Cereb Cortex.* 2007;17(5):1074-84. doi: [10.1093/cercor/bhl018](https://doi.org/10.1093/cercor/bhl018)
 12. Pimentel JT, Inglebret E. Evidence-based practice and treatment efficacy. In: Chermak GD, Musiek FE, editors. *Handbook of central auditory processing disorder.* 2nd ed. San Diego: Plural Publishing; 2014. p. 39-64. (Comprehensive Intervention; vol 2).
 13. Tremblay KL. Beyond the ear: physiological perspectives on auditory rehabilitation. *Semin Hear.* 2005;26(3):127-36. doi: [10.1055/s-2005-916374](https://doi.org/10.1055/s-2005-916374)
 14. Weihing J, Chermak GD, Musiek FE. Auditory training for central auditory processing disorder. *Semin Hear.* 2015;36(4):199-215. doi: [10.1055/s-0035-1564458](https://doi.org/10.1055/s-0035-1564458)
 15. Musiek FE, Chermak GD, Weihing J. Auditory training. In: Chermak GD, Musiek FE, editors. *Handbook of central auditory processing disorder.* 2nd ed. San Diego: Plural Publishing; 2014. p. 157-200. (Comprehensive Intervention; vol 2).
 16. Musiek FE, Baran JA, Pinheiro ML. Duration pattern recognition in normal subjects and patients with cerebral and cochlear lesions. *Audiology.* 1990;29(6):304-13. doi: [10.3109/00206099009072861](https://doi.org/10.3109/00206099009072861)
 17. Zera J, Green DM. Detecting temporal asynchrony with asynchronous standards. *J Acoust Soc Am.* 1993;93(3):1571-9. doi: [10.1121/1.406816](https://doi.org/10.1121/1.406816)
 18. Neubauer H, Heil P. Towards a unifying basis of auditory thresholds: the effects of hearing loss on temporal integration reconsidered. *J Assoc Res. Otolaryngol.* 2004; 5(4):436-58. doi: [10.1007/s10162-004-5031-4](https://doi.org/10.1007/s10162-004-5031-4)
 19. Elliott LL. Backward and forward masking of probe tones of different frequencies. *J Acoust Soc Am.* 1962;34(8):1116-7. doi: <https://doi.org/10.1121/1.1918254>
 20. Musiek FE, Shinn JB, Jirsa R, Bamiou D-E, Baran JA, Zaida E. GIN (Gaps-In-Noise) test performance in subjects with confirmed central auditory nervous system involvement. *Ear Hear.* 2005;26(6):608-18. doi: [10.1097/01.aud.0000188069.80699.41](https://doi.org/10.1097/01.aud.0000188069.80699.41)
 21. Alain C, McDonald KL, Ostroff JM, Schneider B. Aging: a switch from automatic to controlled processing of sounds? *Psychol Aging.* 2004;19(1):125-33. doi: [10.1037/0882-7974.19.1.125](https://doi.org/10.1037/0882-7974.19.1.125)
 22. Sattari K, Rahbar N, Ahadi M, Haghani H. The effects of a temporal processing-based auditory training program on the auditory skills of elderly users of hearing aids: a study protocol for a randomized clinical trial. *F1000Res.* 2020;9:425. doi: [10.12688/f1000research.22757.2](https://doi.org/10.12688/f1000research.22757.2)
 23. Frisina RD. Aging changes in the central auditory system. In: Rees A, Palmer AR, editors. *The Oxford handbook of auditory science: the auditory brain.* 1st ed. Oxford University Press; 2010. p. 417-40.
 24. Loo JHY, Bamiou D-E, Campbell N, Luxon LM. Computer-based auditory training (CBAT): benefits for children with language and reading-related learning difficulties. *Dev Med Child Neurol.* 2010;52(8):708-17. doi: [10.1111/j.1469-8749.2010.03654.x](https://doi.org/10.1111/j.1469-8749.2010.03654.x)
 25. Humes LE, Kinney DL, Brown SE, Kiener AL, Quigley TM. The effects of dosage and duration of auditory training for older adults with hearing impairment. *J Acoust Soc Am.* 2014;136(3):EL224. doi: [10.1121/1.4890663](https://doi.org/10.1121/1.4890663)
 26. Weinstein BE. *Geriatric audiology.* 1st ed. New York: Thieme; 2000.
 27. Medwetsky L, Riddle L, Katz J. Management of central auditory processing disorders. In: Katz J, Medwetsky L, Burkard R, Hood LJ, editors. *Handbook of clinical audiology.* 6th ed. Baltimore: Lippincott Williams & Wilkins; 2009. p. 642-665.
 28. Anderson S, Skoe E, Chandrasekaran B, Kraus N. Neural timing is linked to speech perception in noise. *J Neurosci.* 2010;30(14):4922-6. doi: [10.1523/JNEUROSCI.0107-10.2010](https://doi.org/10.1523/JNEUROSCI.0107-10.2010)
 29. Kraus N, Disterhoft JF. Response plasticity of single neurons in rabbit auditory association cortex during tone-signalled learning. *Brain Res.* 1982;246(2):205-15. doi: [10.1016/0006-8993\(82\)91168-4](https://doi.org/10.1016/0006-8993(82)91168-4)
 30. Talebi H, Moossavi A, Lotfi Y, Faghihzadeh S. Effects of vowel auditory training on concurrent speech segregation in hearing impaired children. *Ann Otol Rhinol Laryngol.* 2015;124(1):13-20. doi: [10.1177/0003489414540604](https://doi.org/10.1177/0003489414540604)
 31. Pichora-Fuller MK, Levitt H. Speech comprehension training and auditory and cognitive processing in older adults. *Am J Audiol.* 2012;21(2):351-7. doi: [10.1044/1059-0889\(2012\)12-0025](https://doi.org/10.1044/1059-0889(2012)12-0025)
 32. Arslantas D, Unsal A, Metintas S, Koc F, Arslantas A. Life quality and daily life activities of elderly people in rural areas, Eskişehir (Turkey). *Arch Gerontol Geriatr.* 2009;48(2):127-31. doi: [10.1016/j.archger.2007.11.005](https://doi.org/10.1016/j.archger.2007.11.005)
 33. Lee TW, Ko IS, Lee KJ. Health promotion behaviors and

quality of life among community-dwelling elderly in Korea: a cross-sectional survey. *Int J Nurs Stud.* 2006;

43(3):293-300. doi: [10.1016/j.ijnurstu.2005.06.009](https://doi.org/10.1016/j.ijnurstu.2005.06.009)