http://dx.doi.org/10.1590/S2317-64312014000200006

Hearing perception of musicians in noisy conditions

Percepção de fala no ruído em músicos

Sávia Leticia Menuzzo Quental[1], Maria Francisca Colella-Santos[2], Christiane Marques do Couto[2]

ABSTRACT

Purpose: To determine whether musical practice improves speech comprehension in noisy conditions. **Methods:** A total 43 female and male subjects aged between 18 and 33 years were distributed into three groups: the Musicians Group, comprising 15 subjects with formal music education; the Intermediate Group, comprising 13 subjects with informal music education; and the Non-musicians Group, comprising 15 subjects without musical experience. The participants had normal hearing thresholds and external and middle ear condition. The Hearing in Noise Test, Brazilian Version, was administered, and the results were analyzed by ANOVA and Chi-Square methods. **Results:** The three groups were normal based on the test standards. There was no statistical difference between the groups overall. In the gender comparison, the only the female participants in the Musician and Intermediate groups differed, and the Intermediate Group performed better. **Conclusion:** Previous musical experience did not influence speech in noise perception.

Keywords: Hearing; Music; Speech perception; Signal-to-noise ratio; Hearing tests

RESUMO

Objetivo: Verificar se o estudo de música pode aprimorar a habilidade de compreensão de fala em presença de ruído. **Métodos:** Participaram deste estudo 43 sujeitos de ambos os gêneros, com idade entre 18 e 33 anos, distribuídos em três grupos: o Grupo de Músicos, composto por 15 sujeitos com estudo formal de música; o Grupo de Intermediários, composto por 13 sujeitos com estudo informal de música e o Grupo de Não Músicos, composto por 15 sujeitos sem experiência musical. Todos os sujeitos encontravam-se dentro dos padrões de normalidade para limiares auditivos e condições de orelhas externa e média. Aplicou-se o teste de compreensão de fala no ruído, *Hearing in Noise Test*, na versão Português do Brasil. Os resultados foram analisados estatisticamente, pelos métodos ANOVA e Qui-quadrado. **Resultados:** Todos os grupos encontraram-se dentro dos valores de normatização do teste. Não houve diferença significativa na análise dos grupos entre si. Na comparação dos resultados, de acordo com o gênero dos participantes, a única diferença observada foi entre os integrantes do gênero feminino dos grupos de Músicos e Intermediários, com melhor desempenho do grupo de Intermediários. **Conclusão:** A experiência musical não influencia no desempenho, em relação à percepção de fala no ruído.

Descritores: Audição; Música; Percepção da fala; Razão sinal-ruído; Testes auditivos

Study done at Rehabilitation and Research Center "Prof. Dr. Gabriel Porto" – CEPRE, Faculty of Medical Sciences, Universidade Estadual de Campinas – UNICAMP – Campinas (SP), Brazil.
(1) Program of Professional Improvement (Specialization) Speech and Hearing Therapy and Hearing Health, Faculty of Medical Sciences, Universidade Estadual de Campinas – UNICAMP – Campinas (SP), Brazil.
(2) Speech and Hearing Therapy Course, Faculty of Medical Sciences, Universidade Estadual de Campinas – UNICAMP – Campinas (SP), Brazil.
Conflict of interests: No
Author's contribution: *SLMQ* main researcher, research elaboration, research development, schedule development, literature survey, data collecting and analysis, article writing, article submission and procedures; *MFCS* co-advisor, research development, schedule development, data analysis, correction of the article writings, approval of the final version; *CMC advisor and* leader, research elaboration, research development, schedule development, data analysis, correction of the article writings, approval of the final version.
Correspondence address: Christiane Marques do Couto. Faculdade de Ciências Médicas, Universidade Estadual de Campinas. R. Tessália Vieira de Camargo, 126, Cidade Universitária "Zeferino Vaz", Campinas (SP), Brasil, CEP: 13083-887. E-mail: cmcouto@fcm.unicamp.br
Received on: 8/12/2013; **Accepted on:** 1/15/2014

INTRODUCTION

An understanding of speech vocalizations is essential for listening, but it is often interrupted by undesirable sounds. Noise pollution is present in most social environments and is caused by electronic devices (radio, TV, computer), car traffic, and non-controllable sounds (factories, construction machinery).

Individuals with normal auditory thresholds can usually distinguish important sounds from dispensable sounds. However, understanding speech also involves the central auditory pathways; therefore, listening in a noisy environment is a complex task, and the integrity of the peripheral auditory pathway alone is not sufficient.

During the central processing of sound, nerve stimuli are transported through several locations until reaching the auditory cortex and other associated cortical areas. Sound interpretation depends on the proper functioning of these structures, and in a noisy environment, the reticular formation is particularly important(1).

The auditory system has been extensively studied since the 1980s, and multiples studies demonstrate the plasticity of both the peripheral and central portions(2). Auditory skills develop through the fine tune adjustment of the brain circuitry based on neural stimulation; the most stimulated or strengthened pathways are maintained, while the less active pathways become atrophied(3). The presence or absence of auditory stimuli can modify the central auditory organization.

One of the fundamental principles of neuroplasticity is the ability to gain skill through repetitive activities, as well as the transfer of cortical enhancements from one region to another similar area(4). In this context, music is an important study target. In addition to influencing cortical behavior(5), the study of music requires regular practice, attention, and listening at a high degree in order to perceive acoustic details. Therefore, musical activity is known to enable cortical reorganization.

There are specific structural and functional differences in cortical activity of musicians and non-musicians, alone or during the execution of auditory tasks, particularly music-related tasks, and between different groups of musicians, categorized by variables such as practice time and the initial age of studies(6). Musical experience allows structural and functional changes in the fine processing of acoustic signals, and as a result, it improves the efficiency in performing daily auditory, such as understanding speech(7).

Along with study and practice, musical appreciation also appears to promote auditory skill development(8). With the potential improvement that these activities may provide in the central auditory system level, music is considered a tool for auditory rehabilitation in patients with central auditory processing disorders(8-10).

It is theorized that musicians may perform better in non-ideal auditory situations compared to people who are not studying music. Therefore, the present study assessed whether the study of music could enhance the ability to understand speech in a noisy environment.

METHODS

This quantitative study was approved by the Research Ethics Committee of the Faculty of Medical Sciences (FCM) at the Universidade Estadual de Campinas (UNICAMP), under opinion 360/2011. Data was collected at the Rehabilitation and Research Center "Prof. Dr. Gabriel Porto", FCM, UNICAMP.

The performance of musicians and non-musicians were compared on an auditory test of understanding speech in noise, called the *Hearing in Noise Test* (HINT), Brazilian Portuguese version.

Subjects were divided into three groups: musicians (GM), which comprised formal music school or university students and graduates; intermediates (GI), which comprised instrumentalists, vocalists, students receiving private music lessons, and autodidacts; and non-musicians (GNM), which comprised people lacking any practical musical experience.

The Intermediates Group was created to cover a larger musician population and detect any influence (formal or informal) of the methodology on the potential auditory perception enhancement. In this study, formal study is defined as study performed under the supervision of a specialized tutor with regularity in practical studies and auditory perception including solfège (reading musical phrases aloud) and music dictation (transcription of music passages from listening), a method typically used by music school and university students. Informal study is defined as study performed in an autodidact manner or under a tutor's supervision without regularity in practical activities and lower frequency or lack of auditory perception activities.

Subjects aged between 18 and 40 years were selected to participate; a sample of young adults was chosen to prevent age-related interference with the participants' performance. The exclusion criteria were the presence of neurological changes, lack of speech fluency, auditory system abnormality, and any syndromes leading to such symptoms.

The inclusion criteria were as follows: concordance with the Free Informed Consent Form (ICF); auditory thresholds up to 25 dB between 0.25 to 8 kHz; and a tympanometric curve type A bilaterally or a tympanometric curve type Ad or Ar if acoustic reflexes were present.

Data collection was carried out in the following order: (1) ICT signature and a brief questionnaire to characterize the GM and GI subjects; (2) meatoscopy; (3) pure tone audiometry and speech audiometry; (4) HINT test with earphones in audiometric cabin; and (5) immittance testing (tympanometry, static compliance, and acoustic reflex testing). Tests were conducted using an otoscope, the Audiometer AC40 (Interacoustics®, with TDH39 earphone for audiometry and speech audiometry), and the Immittance Meter AT235h (Interacoustics®). For the HINT test, a Dell® notebook (Inspiron 1525) was used and included the 7.2 version Hearing Test Device microprocessor, a talkback microphone, TDH39 earphone, and headset microphone that followed the test.

The GM and GI subjects were administered a questionnaire that queried the musical instrument they played initially or for the longest time, their musical experience, practice frequency (instrumental or vocal rehearsal), and performance or auditory perception activity frequency, especially in musical theory classes.

The HINT test was developed by the House Ear Institute (California) and comprises numerous brief sentences of identical difficulty, naturally reproduced and familiar to the audience. The noise used in the test is produced by filtering the acoustic spectrum of the test speech material[11], so that each HINT version possesses its own noise.

HINT-Brazil comprises 12 lists containing 20 sentences each. The sentences are phonetically balanced, and the lists are automatically and randomly selected. Individuals were instructed to repeat the sentences as they understood them, and the responses were graded as follows: correct repetition; word addition by the subject– (e.g., *"The child struck* (with) *his head"*); and an incorrect word addition that did not change the sentence meaning (e.g., "*The little girl plays* with *dolls"* instead of "*The little girl plays dolls").*

HINT can be applied in free field boxes or with earphones (presentation mode selected for this study), and four speech situations were simulated: speech without noise (S), speech with frontal noise (FN), which had noise is present in both ears, speech with noise on the right (RN), and speech with noise on the left (LN). Sentences were present in both ears in all scenarios. Finally, the test software generated the composed noise (CN) from the weighted average of the three noise scenarios[12]. For the present study, we only analyzed the test situations that included a competitive noise: FN, RN, LN, and CN.

The HINT is an adaptive test, that varies the speech stimulus intensity depending on the subject's ability to correctly identify the stimulus: there is a decrease or increase in intensity when the subject responds correctly or incorrectly, respectively. In the competitive noise scenarios, noise intensity was maintained at 65 dB(A), and the speech signal intensity was varied according to the correct speech repetition; speech intensity decreased with each correct response and increased with each error until the test concluded. Initially, the speech intensity was 65 dB(A), the signal-to-noise ratio (S/N) was zero, and during the first four sentences, intensity varied within 4 dB(A). The intensity of the fifth sentence was calculated based on the arithmetic mean between the third and fourth sentence intensities. The intensity between the 5th and the 20th sentences varied within 2 dB(A)[12].

The test results are expressed as the Sentence Recognition Threshold. In situations with noise, the threshold corresponds to the lowest S/N ratio that the subject correctly repeated 50% of the sentences presented[12]. The sentence presentation method maximized the accuracy of the calculated threshold.

The data were compared using the ANOVA method at a 5% significance level ($p<0.05$) between the experimental groups, as well as by gender. The results were verified with the Chi-square test; the absence of a significant difference between the groups was the designated null hypothesis, while a significant difference between the musician, intermediate, and non-musician groups was the designated the non-null hypothesis. We considered two levels of freedom with a (H_0) 5.99 reference value for the null hypothesis.

RESULTS

In total, 43 individuals were evaluated and distributed as follows: GM, n=15, eight men and seven women; GI, n=13, seven men and six women; and GNM, n=15, seven men and eight women. The overall mean participant age was 23 years and ranged 18 to 27 years in the GM group, 19 to 25 years in the GI group, and 20 to 33 years in the MGN group.

Chart 1 summarizes the questionnaire results from the GM and GI groups. The GM group had a higher incidence of auditory perception activity and greater frequency of practical studies compared to the GI group. Most subjects reported playing multiple instruments.

The mean HINT results for each speech scenario are shown in Table 1. Data were compared within each group using the ANOVA test, and no significant difference was observed (Table 2).

Data from two previous studies[13,14] that administered HINT with earphones to Brazilian normal listeners were used as reference for the Chi-square test. All data obtained in the present population were similar to the reported values in both prior surveys (Table 3).

Using ANOVA, same gender subjects were compared between the different groups, and opposite gender subjects were compared within each group. No differences were found in any of the comparisons, except between GM and GI females in the RN scenario. Female GI subjects had a significantly better performance was than the female GM subjects (0.028 *vs.* 0.49619, respectively) (Table 4).

DISCUSSION

Recent studies show that musical training can strengthen neural mechanisms related to auditory attention, within a linguistic context[15]. In a study measuring the variability of cortical auditory evoked responses, there was no difference between musicians and non-musicians asked to focus attention on a single voice among two voices; only the musicians showed less variable cortical responses in the prefrontal

Chart 1. Previous musical experience in the MG and IG groups

Group	n	Gender	Instrument	Experience	Practice frequency	Auditory perception activities
MG	1	M	piano *	19 years	over 3 h a day	RS, MS, HS, MD; "chamber music"
MG	2	M	piano	10 years	up to 1 h a day	RS, MS, HS, MD
MG	3	M	bass guitar	11 years	over 3 h a day	RS, MS, MD
MG	4	F	violoncello	13 years	weekly (1) **	RS, MS
MG	5	M	classic guitar *	10 years	weekly (4)	RS, MS, MD; "choral activities"
MG	6	F	chant	13 years	up to 2 h a day	RS, MS, HS, MD; "tuning training"
MG	7	F	piano	10 years	over 3 h a day	RS, MS, HS, MD
MG	8	F	piano	14 years	weekly (1)	RS, MS, HS, MD; "regency and choral"
MG	9	M	piano *	10 years	weekly (2-3)	RS; "listening and guessing notes"
MG	10	M	guitar	8 years	weekly (3-4)	RS, MS, HS, MD
MG	11	M	piano	4 years	up to 3 h a day	RS, MS, HS, MD; "associate daily sounds to notes"
MG	12	M	bass guitar	13 years	weekly (1)	RS, MS, HS, MD
MG	13	M	bass guitar	6 years	up to 2 h a day	RS, MS, HS, MD
MG	14	F	violin	12 years	weekly (1) **	RS, MS; "choral activities"
MG	15	F	chant	9 years	weekly (5)	RS, MS, HS, MD; "choral activities"
IG	1	M	classic guitar	17 years	weekly (2)	RS, MS, HS; "choral activities"
IG	2	M	violin	10 years	weekly (1) **	RS, MS
IG	3	F	piano	10 years	fortnightly	RS, MS, HS, MD
IG	4	F	chant *	10 years	weekly (1)	RS, MS, HS; "vocalize"
IG	5	M	piano	15 years	weekly (1)	-
IG	6	M	classic guitar	15 years	up to 1 h a day	-
IG	7	F	classic guitar *	7 years	weekly (1)	-
IG	8	M	piano/keyboard *	18 years	up to 1 h a day	RS, MS, HS
IG	9	M	piano/ keyboard	16 years	weekly (1)	RS, MD
IG	10	M	classic guitar *	8 years	fortnightly	-
IG	11	F	piano *	9 years	-	-
IG	12	F	classic guitar *	10 years	weekly (4)	-
IG	13	F	chant/ classic guitar	15 years	weekly (5-6)	MS; "choral activities"

Note: MG = musician group; IG = intermediate group; F = female; M = male; RS = rhythmic solfège; MS = melodic solfège; HS = harmonic solfège; MD = musical dictation
*Reported only playing this instrument. **Currently playing a different instrument than the one reported as the primary. Practical frequency is defined as the number of times that the individual reported playing his/her instrument, for example, “Weekly (5-6)” means “five to six times a week”

Table 1. Average S/N ratios in each groups in four HINT test scenarios

	FN	NR	NL	CN
MG	-4.38	-12.42	-12.113	-8.32
IG	-4.153	-12.323	-12.3	-8.238
NMG	-4.246	-12.606	-12.42	-8.306

Note: MG = musician group; IG = intermediate group; NMG = non-musician group; FN = frontal noise; NR = noise on the right; NL = noise on the left; CN = composed noise; HINT = Hearing in Noise Test

Table 2. Comparison between groups in four HINT test scenarios

	FN	NR	NL	CN
MG X IG	0.5158	0.8604	0.7056	0.7938
MG X NMG	0.6956	0.7167	0.6168	0.9592
IG X NMG	0.7577	0.6558	0.8586	0.8138

ANOVA ($p<0.05$)
Note: MG = musician group; IG = intermediate group; NMG = non-musician group; FN = frontal noise; NR = noise on the right; NL = noise on the left; CN = composed noise

Table 3. Comparison between present study results and results in other studies of Brazilian normal listeners

	FN	NR	N	CNL
Bevilacqua et al.[13]	0.0090	0.9146	0.7207	0.8007
Arieta[14]	0.6468	0.2856	0.7207	0.6873

Chi-square test (H_0=5.99)
Note: FN = frontal noise; NR = noise on the right; NL = noise on the left; CN = composed noise

Table 4. Comparison between the groups by gender in four HINT scenarios

	FN	NR	NL	CN
MG M × IG M	0.5880	0.3141	0.8819	0.3817
MG M × NMG M	0.4959	0.9459	0.6469	0.6135
IG M × NMG M	0.7998	0.3813	0.6042	0.6551
MG F × IG F	0.7055	0.0087 *	0.4533	0.5156
MG F × NMG F	0.8515	0.4270	0.7780	0.6149
IG F × NMG F	0.5589	0.3310	0.5077	0.7895
MG M × MG F	0.3919	0.0730	0.7133	0.1540
IG M × IG F	0.3114	0.3778	0.6253	0.8248
NMG M × NMG F	0.9171	0.4308	0.5488	0.5646

ANOVA ($p<0.05$)
Note: MG = musician group; IG = intermediate group; NMG = non-musician group; FN = frontal noise; NR = noise on the right; NL = noise on the left; CN = composed noise; M = male gender, F = female gender (ex: "MG F" means females in the musician group)

cortex. This region is important in maintaining attention in noisy environments, therefore the authors concluded that musical training may directly influence the auditory attention ability, suggesting that this activity could be used for rehabilitation in individuals with learning disabilities caused by attention deficits.

The ability of musical experience to improve speech interpretation in noisy environments has been investigated previously; tasks performed by musicians such as distinguishing one instrument among many or achieving the exact note on a violin are similar to the cortical activities performed to discern speech from noise[16]. The distinction of acoustic, frequency (*pitch*), and time variation patterns enable this task, and musical experience seems to favor these particular auditory processes.

A study was conducted using the *Difference Limen for Intensity* (DLI), *Difference Limen for Frequency* (DLF), and *Gaps in Noise* (GIN) psychoacoustic tests, which assess the differential thresholds of intensity, frequency, and temporal resolution, respectively, with musicians and non-musicians. Authors observed a slight difference between the groups, with better performance in the musicians, especially in the DLI test, which illustrates their stronger auditory perception[17].

In this study, several individuals, especially in the GM group, stated that sentences with intonational variation, exclamatory, or word emphasis were more easily recognized. Although this possibility was not explored, in different phrases with an identical S/N, we observed that subjects more often correctly repeated the phrase that was more emphatic or of inconstant prosody. In addition, GM individuals stated that words with high frequency phonemes, such as /s/ e /ʃ/, were more clearly defined. Both observations illustrate how the perception of acoustic details affects the ability to understand speech in noise and confirm the potential advantage musicians have in speech tests, although this hypothesis was not illustrated.

When assessing speech perception, selecting the most appropriate test is a delicate task. Although speech audiometry tests are part of the basic audiologic examination, the typical test conditions do not accurately reflect daily speaking situations and, therefore, may not fully evaluate speech perception or may disregard complex scenarios. Thus, tests with sentences (the HINT test, for example) and competitive noise are administered and assumed to more closely simulate reality. Compared to other tests, the HINT test is unique in the type of noise used, which is produced from the speech material spectrum and applied equally throughout its application.

In Brazil, the test is standardized to the following reference values for earphones: -4.6 dB, -12.1 dB, -12.2 dB, and -8.4 dB, for the FN, RN, LN, and CN scenarios, respectively. Another study[14] conducted on normal listeners with earphones observed values similar to standardization, -5 dB, -12.3 dB, -2.4 dB, and -8.7 dB for the FN, RN, LN, CN scenarios, respectively. The present study results are also close to the reference values, indicating the normality of the participants.

The HINT test was created to assess auditory performance in hearing aid users[12], but it has also been used to study auditory performance differences in specific populations, such as children[18], cochlear implant users[19,20], workers exposed to noise[14] and chemicals[21], airmen[22], bilingual individuals[23], and musicians.

A previous study[24] evaluated musicians who began training at age 7 and played at least 10 years and non-musicians by administering the HINT noise and QuickSIN - a test that combines *four-talker babble* noise with non-adaptive presentation of sentences[25] - as well as testing the working memory and frequency discrimination. The musicians reportedly performed better in the QuickSIN test and in the frontal noise scenario in the HINT test. The musicians also showed better performance in working memory and in frequency discrimination. In addition, there was a moderate correlation between the HINT test and working memory, and there was no correlation between the HINT test and frequency discrimination.

The aforementioned study explained the differences between the groups based on the Reverse Hierarchy Theory and a phenomenon known as *glimpsing.* The Reverse Hierarchy theory suggests that a sound stimulus is perceived through a reverse hierarchy; the stimulus is initially understood as a whole, and then the acoustic details become evident[26]. Thus, as the listening situation becomes difficult, for example, the S/N ratio becomes smaller, the perception of competitive information is avoided. As shown in the study, working memory can be enhanced more easily through music study.

The phenomenon known as *glimpsing* is the listener's ability to use background noise gaps to distinguish the voice providing relevant information from other disruptive voices[24]. Musicians better perceive frequency, timbre, and time intervals, which can contribute to voice differentiation when there is background noise such as babble noise used in the QuickSIN test. However, the HINT test uses background noise created from the spectrum of test sentence pronunciations, which does not favor subjects with a stronger glimpsing ability and explains the similarity between the groups in studies of RN, LN, and CN situations, as well as the similarity between the groups in this study. Presumably, the difficulty in completing the HINT test is equal between the groups but may differ (easier for musicians) according to the type of noise.

Based on the better performance of musicians compared to non-musicians in speaker noise tests, such as the babble noise, and the similar performances between these groups in white noise tests, such as the noise used in HINT, it can be inferred that for concurrent meaningful sounds, even if unintelligible (babble noise), stronger auditory perception would improve performance, revealing differences between the groups. Because we are evaluating distinct auditory abilities, such as auditory closure during white noise and figure-background ability when the noise is composed of voices[27], we concluded that musical practice appears to significantly benefit only one ability.

However, another study[28] reported different findings in the musicians' performance during white noise scenarios. The List of Portuguese Sentences[29] test, used to generate the Sentence Recognition Threshold in Silence (SRTS) and in Noise (SRTN), was administered to 55 musicians and 45 non-musicians, and a significant difference was observed in SRTN, favoring the musicians. As a result, the authors encouraged the use of music as an auditory training therapy in patients with difficulty interpreting speech.

The List of Portuguese Sentences was developed in Brazil and similar to HINT, uses noise produced from speech material[29]. When administered using earphones, an average SRTN of -5.29 dBNA (equivalent HINT's CN situation) was observed in normal listeners[30]. Despite the similarity to HINT, the normalization values of the two tests are quite different, which may indicate a distinction between them, possibly caused by the noise and sentence presentation. This factor may explain the discordant results between the present study and a prior study[24].

Despite the benefits that musical experience brings to auditory perception, there was generally no difference observed between groups in this study. This likely reflects the involvement of other cognitive abilities during the HINT test, such as memory[26] and attention, other than purely auditory functions. Because these abilities were not assessed, it was not possible to infer participant similarity in this respect.

The musicians in the aforementioned study[28] were members of the same musical bands and, therefore, had musical rehearsals prior to the study. By analyzing the population demographics of the present study (Chart 1), there is a clear variation in practice frequency, even in subjects within the same group. Thus, we suspect that greater homogeneity within the groups may have produced a significant difference in the results.

The only statistical difference observed was in a single HINT test scenario compared between women in the GM and GI groups. The ANOVA test considers the standard deviation beyond the mean group values, and, as reported earlier, we observed a less variation between the GI group women and the GM group women. We did not detect any influence from the study characteristics or practice frequency in the two subgroups that would explain this difference, which confirms that greater group homogeneity produces different results. A larger dataset could also demonstrate tendencies between the three groups.

Alternatively, the lack of difference between the groups may simply reflect the participants' normal hearing. All of the participants were within the normal range for the HINT test and thus have similar abilities being tested; this can mask differences between the groups. Research of musicians and non-musicians with hearing loss who are unable to perceive speech normally in unfavorable conditions could clarify this question.

CONCLUSION

Musical training did not influence the ability of aurally normal individuals to understand speech in noise evaluated using the HINT test.

ACKNOWLEDGEMENTS

The authors thank Fga. Aline de Moraes Arieta and Prof. Dr. Everardo Costa for providing the HINT equipment and their special contribution of information and test clarification.

REFERENCES

1. Teixeira CF, Griz SMS. Sistema auditivo central. In: Bevilacqua MC, Martinez MAN, Balen SA, Pupo AC, Reis ACMB, Frota S, organizadores. Tratado de audiologia. São Paulo: Santos; 2011. p. 17-28.
2. Féres MCLC, Cairasco NG. Plasticidade do sistema auditivo. Rev Bras de Otorrinolaringol. 2001;67(5):716-20. http://dx.doi.org/10.1590/S0034-72992001000500018
3. Northern JL, Downs MP. Audição na infância. 5a ed. Rio de Janeiro: Guanabara-Koogan; 2005. Capítulo 5, Desenvolvimento auditivo e intervenção precoce; p. 103-28.
4. Kleim JA, Jones TA. Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. J Speech Lang Hear Res. 2008;51(1):S225-39. http://dx.doi.org/10.1044/1092-4388(2008/018)
5. Sacks O. The power of music. Brain. 2006;129(10):2528-32. http://dx.doi.org/10.1093/brain/awl234
6. Münte TF, Altenmüller E, Jäncke L. The musician's brain as a model of neuroplasticity. Nature Rev Neurosci. 2002;3(6):473-8. http://dx.doi.org/10.1038/nrn843
7. Kraus N, Chandrasekaran B. Music training for the development of auditory skills. Nature Rev Neurosci. 2010;11(8):599-605. http://dx.doi.org/10.1038/nrn2882
8. Freire KGM. Treinamento auditivo musical: uma proposta para idosos usuários de próteses auditivas [tese de doutorado]. São Paulo: Universidade Federal de São Paulo; 2009.
9. Mendonça JE, Lemos SMA. Relações entre prática musical, processamento auditivo e apreciação musical em crianças de cinco anos. Rev ABEM. 2010;(23):58-66.
10. Eugênio ML, Escalda J, Lemos SMA. Desenvolvimento cognitivo, auditivo e linguístico em crianças expostas à música: produção de conhecimento nacional e internacional. Rev CEFAC. 2012;14(5):992-1003. http://dx.doi.org/10.1590/S1516-18462012005000038
11. Nilsson M, Soli SD, Sullivan JA. Development of the Hearing in Noise Test for the measurement of speech reception thresholds in quiet and in noise. J Acoust Soc Am. 1994;95(2):1085-99. http://dx.doi.org/10.1121/1.408469
12. HINT – Bio-logic Systems Corp. HINT Pro: Hearing in Noise Test: user's and service manual. Mudelen: Bio-logic Systems Corp. 2006.
13. Bevilacqua MC, Banhara MR, Costa EA, Vignoly AB, Alvarenga KF. The Brazilian Portuguese hearing in noise test. Int J Audiol. 2008;47(6):364-5. http://dx.doi.org/10.1080/14992020701870205
14. Arieta AM. HINT Brasil: estudo em portadores de perdas auditivas [tese de doutorado]. Campinas: Universidade Estadual de Campinas; 2013.
15. Strait DL, Kraus N. Can you hear me now? Musical training shapes functional brain networks for selective auditory attention and hearing speech in noise. Front Psychol. 2011;2:113. http://dx.doi.org/10.3389/fpsyg.2011.00113.
16. Anderson S, Kraus N. Neural encoding of speech and music: implications for hearing speech in noise. Semin Hear. 2011;33(2):207-12. http://dx.doi.org/ 10.1055/s-0032-1313725
17. Quental SLM, Couto CM. Análise de características psicoacústicas em músicos [trabalho de conclusão de curso] Campinas: Universidade Estadual de Campinas; 2011.
18. Jacob RTS, Monteiro NFG, Molina SV, Bevilacqua MC, Lauris JRP, Moret ALM. Percepção de fala em crianças em situação de ruído. Arq Int Otorrinolaringol. 2011;15(2):163-7. http://dx.doi.org/10.1590/S1809-48722011000200007
19. Friesen LM, Shannon RV, Baskent D, Wang X. Speech recognition in noise as a function of the number of spectral channels: comparison of acoustic hearing and cochlear implants. J Acoust Soc Am. 2001;110(2):1150-63. http://dx.doi.org/10.1121/1.1381538
20. Danieli F, Bevilacqua MC. Reconhecimento de fala em crianças usuárias de implante coclear utilizando dois diferentes processadores de fala. Audiol Commun Res. 2013;18(1):17-23. http://dx.doi.org/10.1590/S2317-64312013000100005
21. Fuente A, McPherson B, Muñoz V, Pablo Espina J. Assessment of central auditory processing in a group of workers exposed to solvents. Acta Otolaryngol. 2006;126(11):1188-94. http://dx.doi.org/10.1080/00016480600681585
22. Ribera JE. Functional hearing in noise: insert earphones vs. supra-aural headphones. Aviat Space Environ Med. 2007;78(12):1159-61. http://dx.doi.org/10.3357/ASEM.2077.2007
23. Weiss D, Dempsey JJ. Performance of bilingual speakers on the English and Spanish versions in Hearing in Noise Test (HINT). J Am Acad Audiol. 2008;19(1):5-17. http://dx.doi.org/10.3766/jaaa.19.1.2
24. Parbery-Clark A, Skoe E, Lam C, Kraus N. Musician enhancement for speech-in-noise. Ear Hear. 2009;30(6):653-61. http://dx.doi.org/10.1097/AUD.0b013e3181b412e9
25. Killion MC, Niquette PA, Gudmundsen GI. Development of a quick speech-in-noise test for measurement signal-to-noise ratio loss in normal hearing and hearing-impaired listeners. J Acoust Soc Am. 2004;116(4):2395-405. http://dx.doi.org/10.1121/1.1784440
26. Ahissar M, Nahum M, Nelken I, Hochstein S. Reverse hierarchies and sensory learning. Phil Trans R Soc B. 2009;364(1515):285-99. http://dx.doi.org/10.1098/rstb.2008.0253
27. Pereira LD, Schochat E. Processamento auditivo central: manual de avaliação. São Paulo: Lovise; 1997.

28. Soncini F, Costa MJ. Efeito da prática musical no reconhecimento da fala no silêncio e no ruído. Pró-Fono Rev Atual Cient. 2006;18(2):161-70. http://dx.doi.org/10.1590/S0104-56872006000200005
29. Costa MJ. Listas de sentenças em português: apresentação e estratégias de aplicação na audiologia. Santa Maria: Pallotti, 1998.
30. Costa MJ, Daniel RC, Santos SN. Reconhecimento de sentenças no silêncio e no ruído em fones auriculares: valores de referência de normalidade. Rev CEFAC. 2011;13(4):685-91. http://dx.doi.org/10.1590/S1516-18462010005000114