

Tinnitus, Medial Olivocochlear System, and Music Exposure in Adolescents

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Abstract

Introduction: The most common cause of tinnitus is the exposure to noise; in the case of adolescents, music is the main sound source they are exposed to. Currently, one of the hypotheses about the genesis of tinnitus is related to the deterioration in the functioning of the medial olivocochlear system (MOCS). **Aim:** The aim of this study was to determine the presence or absence of tinnitus in adolescents with normal hearing and to relate it to: (a) the functioning of the MOCS, by the contralateral suppression of the transient evoked otoacoustic emissions (TEOAEs) and (b) the musical general exposure (MGE). **Materials and Methods:** A cross-sectional descriptive correlational study was conducted. The sample was composed by adolescents with ages between 14 and 15. Two questionnaires were administered, one in relation to the subjective report of tinnitus and the other in relation to recreational activities to know the MGE. **Results:** The results showed that the amplitude of frequencies (1000, 1500, 2000, and 3000 Hz) and global amplitude of TEOAEs, with and without acoustic contralateral stimulation, were higher in the group without tinnitus, with a statistically significant difference ($P < 0.05$). The suppressive effect was higher in the group without tinnitus; however, there was no statistically significant difference. Contrastingly, a significant association ($P < 0.05$) between exposure to music and tinnitus was observed; 72.41% of the adolescents with high exposure to music had tinnitus. **Discussion and Conclusion:** The results of the present investigation provide a contribution to the hypothesis of “the participation of the MOCS.” Furthermore, a high MGE can be considered a risk factor for the onset of tinnitus.

Keywords: Adolescents, contralateral suppression of the transient evoked otoacoustic emissions, medial olivocochlear system, musical general exposure, tinnitus

INTRODUCTION

Tinnitus is a highly prevalent condition and an unresolved issue in population auditory health. It has traditionally been defined as the perception of sound in the absence of an external sound stimulus, which is not a disease in itself, but a symptom^[1] that can respond to various causes, not necessarily associated with hearing loss,^[2] because tinnitus can also occur in patients with normal hearing thresholds.^[3,4]

Epidemiological studies associate the occurrence of tinnitus with hearing loss induced by noise.^[5] In a study conducted by Penner *et al.*,^[6] noise exposure was the most frequent cause for the occurrence of tinnitus. In the case of adolescents, music constitutes the main sound source, which they are exposed to, whether at home, in clubs, in live concerts, meetings, discos, or through personal music players.^[7] When this exposure to music takes place at high noise

levels and for long periods of time, it constitutes a real hearing health risk. In studies conducted in this age group, a progressive increase with age in the participation of recreational activities related to music, characterized by high noise levels accompanied with an increase in tonal thresholds, is observed.^[8-15]

There are several hypotheses that attempt to explain the pathophysiology of tinnitus. These hypotheses are divided into two groups: cochlear mechanisms and noncochlear mechanisms. The first group believes that the etiology of tinnitus is located in the cochlea isolated from the rest of the

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auditory pathway, whereas the second group emphasizes the retrocochlear and central aspects in regard to the generation and persistence of tinnitus, without excluding the role of the cochlea.^[16] Taking into account of the noncochlear mechanisms, tinnitus has been defined by Jastreboff^[17] as “the perception of sound that results exclusively from an activity within the nervous system without any corresponding mechanical, vibratory activity within the cochlea, and not related to external stimulation of any kind.” Within the noncochlear hypothesis is the one concerning “the participation of the medial olivocochlear system (MOCS).”^[18,19]

This hypothesis states that one of the MOCS dysfunctions may produce an alteration in the modulation of outer hair cells, causing an imbalance between hyperpolarization and depolarization, which causes an abnormal and exaggerated electrical activity that is misinterpreted by the central nervous system as a sound.^[18-20]

Rasmussen,^[21] in 1946, detailed the trajectory of a group of efferent neurons, the efferent auditory pathway, which originates in the brainstem and that ends its trajectory in the cochlea. Afterwards, in the late 1970s, Warr and Guinan^[22] showed that the efferent auditory pathway was made up of two distinct neuronal subpopulations, and classified it into two subtypes: the previously mentioned MOCS and the lateral olivocochlear system. The MOCS originates in the brainstem, in the medial superior olivary complex, intersects at floor level of the fourth ventricle, and goes to the contralateral cochlea, specifically at the level of the organ of Corti. It innervates the bases of the outer hair cells, causing their hyperpolarization.^[23]

Currently, the study of this pathway and its possible relationship with the generation of tinnitus continues, evaluating its performance by contralateral suppression (CS) test of otoacoustic emissions (OAEs). This study can be applied in various types of OAEs, the transient evoked otoacoustic emissions (TEOAEs) and distortion product otoacoustic emissions (DPOAEs) being the most studied ones.

In the CS of the OAEs, two measurements of the amplitude of OAEs are performed, one without contralateral acoustic stimulation (CAS) and the other with CAS; the difference between the two amplitudes is called suppression effect. In the case of an ear that does not present alterations, and that present an unscathed MOCS, the OAEs amplitude is reduced in the presence of an acoustic stimulation; therefore, the suppressive effect is a phenomenon that occurs as a consequence of the normal functioning of the MOCS, and its absence can be considered as a pathological finding that indicates an alteration of the system, which can be related to diverse dysfunctions, the presence of tinnitus being one of them.^[24]

Researches consider the hypothesis of the participation of the MOCS^[18,19] and compare the TEOAEs or DPOAEs suppression in groups without and with tinnitus. In some cases, obtain non-statistically significant difference between the two groups in terms of the amplitude response of the

TEOAEs and suppressive effect.^[25] Contrastingly others studies show a statistically significant difference in one or more evaluated frequencies with less intense suppression registered in the tinnitus group.^[22,26-27]

The hypothesis of the present research is that the majority of the adolescents with tinnitus have a less suppressive effect and a lesser amplitude of TEOAE than the adolescents without tinnitus; and that the adolescents who participate in recreational activities with high exposition to music have more presence of tinnitus than the adolescents with low or moderate exposure.

Most of the studies shown in the literature have been conducted in North American and European countries and, therefore, may be of interest to show results obtained in a country of South America, such as Argentina.

This research was conducted in the framework of the Program for the Conservation and Promotion of Hearing Among Adolescents within a specific line of research for the study of MOCS and its diverse clinical and research applications, implemented in the Center for Research and Transfer in Acoustics (CINTRA), Associated Unit of CONICET, National Technological University (UTN), Córdoba Regional Faculty, Argentina.

Aims

The aim of this study was to determine the presence or absence of tinnitus in adolescents with normal hearing and to relate it to: (a) the functioning of the MOCS, by the CS of TEOAEs, and (b) the musical general exposure (MGE).

MATERIALS AND METHODS

This research was conducted with a cross-sectional descriptive correlational design.

Participants

The study was conducted in technical schools with the consent of the Ministry of Education of the Province of Córdoba. The participants were 77 adolescents, aged 14 and 15 years (average 14.3 years). The population is characterized by a mixture of Caucasians and indigenous peoples from the city of Córdoba, Argentina.

The adolescents received their parents'/tutors' written consent. The study's inclusion criteria were:

- (1) Normal otoscopic examination.
- (2) Tympanometry with normal function of the middle ear, in terms of pressure and compliance.
- (3) TEOAEs present in both ears.
- (4) Audiometry in the conventional frequency range (250–8000 Hz) and an extended high frequency audiometry (8000–16,000 Hz) within the parameters considered normal.

For this analysis, data of the adolescents who had some hearing pathology at the moment of the examination were excluded.

Audiological assessment

The audiological evaluation took place in a personalized way, lasting approximately between 30 and 40 min per participant, preferably in the morning time allowing a prior auditory rest. The audiological study was conducted in an utilitarian vehicle adapted as a mobile audiometric booth, acoustically conditioned, that complied with the environmental requirements of the national legislation IRAM 4028-1:1992^[28] and international legislation ISO 82531-1:2010^[29] in relation to the external sound isolation and the inner sound absorption.^[15]

The evaluation consisted of the application of the tests described below:

- (1) Auditory State Questionnaire: referred to the issues that might affect hearing function and subjective report of tinnitus (presence or absence, frequency of occurrence, and duration).
- (2) Otoscopy: to assess the condition of the ear canal and tympanic membrane. An otoscope Heine Beta 100 was used.
- (3) Tympanometry: to objectively assess changes in air pressure in the middle ear. A tympanometry within normal parameters was considered in the presence of a type A tympanogram, following Jerger's classification.^[30] An automatic middle ear "Minitymp" Kamplex MT10 Interacoustics analyzer was used.
- (4) Audiometry in the conventional frequency range and extended high frequency audiometry: to determine the auditory threshold in conventional frequencies (250–8000 Hz) and in the extended range (8000–16,000 Hz), using the bracketing method specified by the ISO 8253-1:2010^[29] standard. Both ears were assessed with pure tones with intensity variations of 3 dB HL, instead of the 5 dB HL traditionally used, to obtain greater precision. Adolescents with thresholds ≤ 21 dB HL at each frequency analyzed in both ranges were included in the sample. A digital audiometer Madsen, model Orbiter 922 DH/1 was used. Its calibration was controlled three times a year: in the conventional range according to the ISO 389-1:1998^[31] and IRAM 4075:1995^[32] standards, using an artificial ear Brüel and Kjaer type 415, equipped with a standard microphone Brüel and Kjaer type 4134, traceable to the reference standards of the European Community.^[33] In addition, a set of Sennheiser supra-aural earphones for both audiometric ranges calibrated according to ISO 389-8:2004^[34] standard was used. The application force of the headband (10.3 N) complies with the specifications of ISO 389-5:2006^[35] standard (10.0 ± 1.0 N).
- (5) TEOAEs: to detect mechanical cochlear status. It was evaluated with a nonlinear click stimulus of 260 presentations, with an intensity of 80 dB pk, with the peak noise rejection level of 47.3 dB SPL. The stability of the stimulus was maintained $\geq 85\%$. The studied frequencies were 1000, 1500, 2000, 3000, and 4000 Hz. The TEOAEs were considered present in

both ears when the whole reproducibility level was $\geq 70\%$ and the SNR ≥ 6 dB SPL in at least three of the studied frequencies. An Otodynamics Ltd DP ECHOPORT ILO 292 USB II (Otodynamics Ltd.), United Kingdom) equipment with UGD TEOAEs Probe and an ILO V6 OAE clinical analysis and data management software were used.

- (6) CS of TEOAEs: to analyze the suppression effect, for which the TEOAEs were repeated with CAS, using white noise at 50 dB that was generated by a Madsen Orbiter 922 audiometer through a probe EAR TONE A3. The suppressive effect was considered present when the difference between the global amplitude of the TEOAEs with and without acoustic stimulation was > 0 dB.

Musical general exposure assessment

A questionnaire was administered to establish in detail the different types of musical recreational activities among the adolescents. This aspect was assessed applying the "out-of-school activities questionnaire" that was elaborated by Schuschke, Rudloff, Penk, and their work group,^[36] from the University of Otto von Guericke of Magdeburg, Germany. This questionnaire was adapted for Argentinean population by Serra *et al.*^[14] following the methodology of direct and inverse translation consisting of the translation into Spanish, a systematic review of the content of the instrument and the research team's discussion, a reverse translation to the original German language and a new content analysis of it.

Psychologists administered the questionnaire collectively during school hours. Detailed instructions about how to complete the survey were provided, and the students were given the opportunity to ask questions. The duration was approximately 20 min.

The dimensions of the questionnaire were related with the participation in five different music recreational activities: (a) Exposure to music at home; (b) Playing a musical instrument and being part of a musical group; (c) Live concert attendance; (d) Nightclub attendance; and (e) Use of personal music players.

The questionnaire asks how often the adolescents participate in each activity, since when, the time dedicated to each, and the self-reported relative sound levels they are exposed to, thus obtaining a "participation level" for each activity (does not participate, low level, medium level, and high level). From the combination of participation levels in the five musical activities, three categories of MGE were obtained:

- (1) Low exposure to music, made up of "does not participate" and "low level of participation" in all recreational activities.
- (2) Moderate exposure to music, composed of a "medium level of participation" in one or more recreational activities.
- (3) High exposure to music, which includes a "high level of participation" in two or more recreational activities.

Statistical analysis

The data were analyzed using parametric and nonparametric statistical analysis using the ear as the analysis unit. One-way analysis of variance was applied to analyze the effect of the presence of tinnitus on the amplitude per frequency and on the global amplitude in the instances with and without CAS. To analyze the differences of the suppressive effect, the Wilcoxon test was used in independent samples. Contingency tables were used for the analysis of the association between categories of MGE and groups with presence or absence of tinnitus, applying chi-square tests. In every case, a significance level of 5% ($P < 0.05$) was considered.

The statistical analyses were performed using the Statistical Package for the Social Sciences version 17.0 software (SPSS Inc., Chicago, IL, USA) software and InfoStat version 2015 (Group Info Stat, FCA, Universidad Nacional Córdoba, Argentina).^[37]

RESULTS

The results obtained by the Auditory State Questionnaire showed that 64% of the adolescents participants had tinnitus ($n = 49$), whereas 36% had no tinnitus ($n = 28$). In Table 1, the distribution of the frequency of occurrence and duration of tinnitus in the evaluated adolescents is shown. Regarding the symptom's frequency of occurrence, 85.7% reported an occasional appearance, 10.2% reported weekly occurrence, and 4.1% reported daily occurrence. As to the duration, 73.5% claimed a duration of approximately 10 min, 20.4% a shorter than 10 min duration, and 6.1% indicated a duration that ranged between 10 min and an hour. This shows that most adolescents manifested an occasional frequency of occurrence and a duration of approximately 10 min. Inferential analysis showed no statistically significant difference between the suppressive effect and the hearing thresholds of the right and left ear; thus, no differentiation between them was made in subsequent analysis. The results of the TEOAEs with and without CAS are shown in Figures 1 and 2.

Figure 1, which refers to the TEOAEs without CAS, shows that the average amplitude of each evaluated frequency was higher in the group without tinnitus, with the exception of the frequency 4000 Hz. A significant effect of the presence of tinnitus in the 1000 Hz frequency without CAS ($F_{1,152} = 9.23$; $P = 0.0028$; $\eta^2 = 0.06$) was observed.

Table 1: Distribution of the frequency of occurrence and duration of tinnitus			
Tinnitus: characteristics		n	%
Frequency	Occasional	42	85.7
	Weekly	5	10.2
	Daily	2	4.1
Duration	10 min	36	73.5
	<10 min	10	20.4
	10 min to 1 h	3	6.1

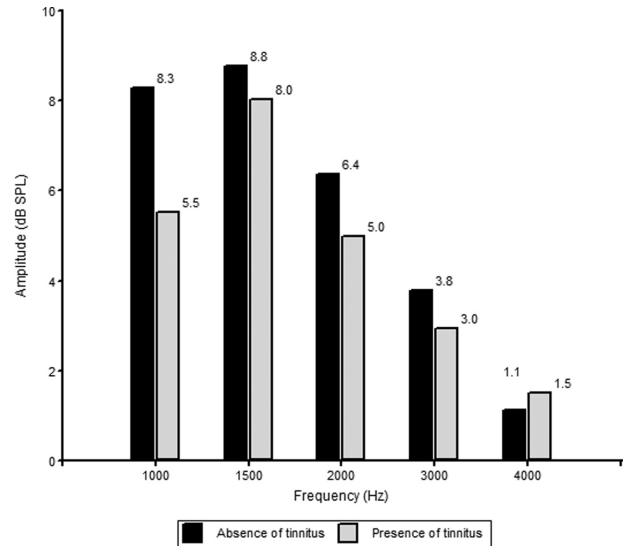


Figure 1: Average of amplitude per frequency in the TEOAEs without CAS in adolescents with and without tinnitus

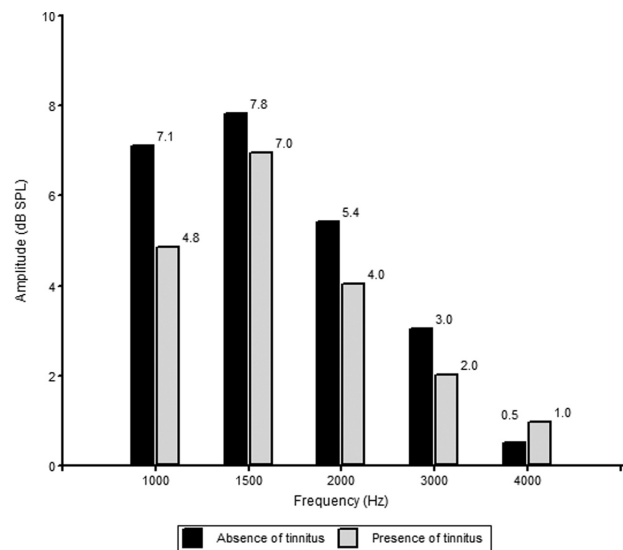


Figure 2: Average of amplitude per frequency in the TEOAEs with CAS in adolescents with and without tinnitus

Figure 2, which refers to the TEOAEs with CAS, shows that the average amplitude of each frequency was higher in the group without tinnitus, with the exception of frequency 4000 Hz. At the same time, similar to the results found without CAS, a significant effect of the presence of tinnitus in frequency 1000 Hz with CAS ($F_{1,152} = 6.77$; $P = 0.01$; $\eta^2 = 0.04$) was observed.

Figure 3, which refers to the global amplitude of the TEOAEs in conditions without and with CAS, shows a significant effect of the presence of tinnitus in the global amplitude of the TEOAEs without CAS ($F_{1,152} = 4.78$; $P = 0.03$; $\eta^2 = 0.03$) and with CAS ($F_{1,152} = 3.94$; $P = 0.05$; $\eta^2 = 0.025$). In comparison with the group with tinnitus, the global amplitude was higher in the group without tinnitus.

Figure 4 shows the results obtained from the CS study of the TEOAEs. The suppressive effect was >0 dB in both groups.

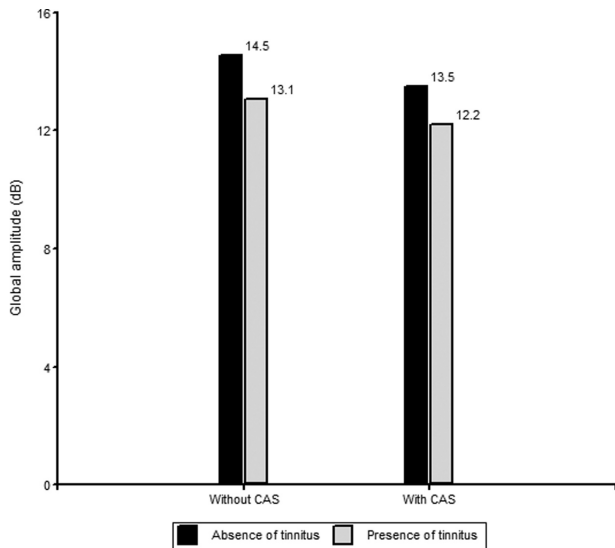


Figure 3: Global amplitude in conditions with and without CAS in adolescents with and without tinnitus

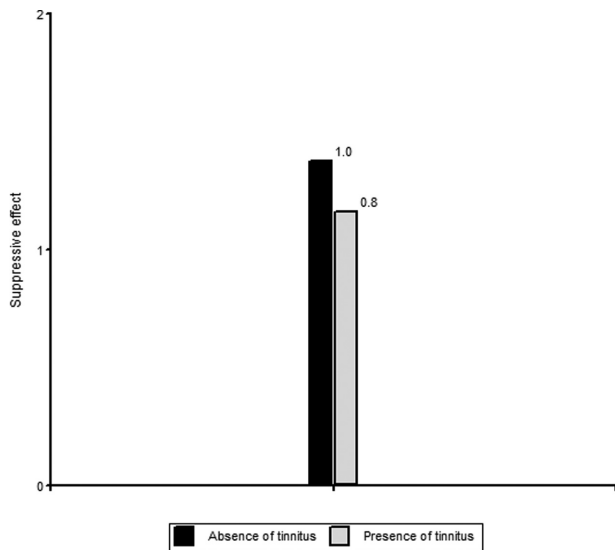


Figure 4: Suppressive effect of the TEOAEs in adolescents with and without tinnitus

However, the group without tinnitus got a higher value of the suppressive effect (1.03 dB SPL) than the group with tinnitus (0.79 dB SPL), although the difference between both values was not statistically significant.

The analysis of the MGE showed 37.7% of the adolescents with a high MGE, 32.5% with a moderate MGE, and 29.9% with a low one. Table 2 shows the distribution of the adolescents' exposure to music in relation to the tinnitus, and a significant association ($P = 0.0191$) was found. The category with the most significant difference between the absence and presence of tinnitus was the one with the highest exposure to music, in which 72.4% of the adolescents showed the presence of tinnitus, whereas the remaining 27.6% belonged to the group without tinnitus. It is important to highlight that the low category of MGE had a higher percentage of presence of tinnitus (69.6%) than that of the moderate category of MGE (48.0%).

Table 2: Distribution of the musical general exposure of adolescents with and without tinnitus

Tinnitus	Musical general exposure (MGE)							
	Low		Moderate		High		Total	
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	<i>N</i>	%
Presence	32	69.6	24	48.0	42	72.4	98	63.6
Absence	14	30.4	26	52.0	16	27.6	56	36.4
Total	46	100	50	100	58	100	154	100

Discussion and Conclusion

The aim of this study was to determine the presence or absence of tinnitus and to relate it to the functioning of the MOCS, by the CS of TEOAEs, and the MGE. This study was conducted in adolescents with normal hearing; however, a group of them reported the presence of tinnitus with different frequencies of occurrence and duration, whereas the other group did not show this symptom at all.

Regarding the response of the TEOAEs in conditions with and without CAS, the analysis of the average global amplitude showed higher values in the group without tinnitus than on the one with tinnitus. The difference between the groups in both conditions was statistically significant, which suggests a higher response of the outer hair cells in the presence of sound stimulation in adolescents without tinnitus. These results are according to the ones obtained by Mor and de Azevedo,^[25] who evaluated 19 patients between the ages of 20 and 64 years with unilateral tinnitus and normal audiometric thresholds, using a similar procedure to the one used in the present investigation with the exception of the 60 dB intensity in the CAS instead of 50 dB. Their results showed that the global response levels of the TEOAEs of the ears without tinnitus were higher, and that the functioning of the MOCS, which was evaluated through the use of the CS of the TEOAEs, was more efficient.

The analysis of the amplitude per frequency of the TEOAEs with and without CAS showed a higher response in the group of adolescents without tinnitus in the frequencies 1000, 1500, 2000, and 3000 Hz, with a statistically significant difference in the 1000 Hz frequency. Cruz Fernandes and Momensohn dos Santos^[26] studied the suppressive effect implementing CS of the TEOAEs in a group of women between the ages of 18 and 59 years with tinnitus and normal hearing in comparison with a control group of the same age but without tinnitus. They implemented the CAS with an intensity of 50 dB provided by an audiometer, as in the present research. Its results showed a statistically significant difference in the 1000 Hz frequency of the left ear in the group with tinnitus in comparison with the control group. Furthermore, the results provided by Geven *et al.*^[19] showed subtle differences in the 2000 and 2800 Hz frequency bands in the right ear, indicating a higher suppression in the control group than in the group with tinnitus. These results could be related with a higher innervation of the MOCS in the 1000–2000 Hz range.^[38]

In the analysis of amplitude per frequency of the TEOAEs with and without CAS, it is necessary to highlight the 4000 Hz frequency, because it is the only one in which lower values were found for the group without tinnitus in comparison to the one with tinnitus. For future researches, it is important to particularly examine around the 4000 Hz frequency related to tinnitus and music exposure.

With respect to the relation between MGE and the presence of tinnitus, the results showed a significant association ($P=0.0191$). It should be noted that a group of adolescents who participated in the study showed a high MGE (37.66%), and that in this category, 72.41% of the adolescents reported the presence of tinnitus. The adolescents in the sample were between the ages of 14 and 15 years, and according to previous investigations,^[8-10,12,14] this exposure may increase over time. For this reason and with the purpose of preventing permanent hearing damage, it is highly important to take steps for prevention and promotion activities about hearing health for this age group.

The inclusion of tinnitometry is suggested for future studies, because it may provide data about the characteristics of tinnitus. In this way, it could contribute to more specific analysis in relation to the tone in which tinnitus is perceived and its relations to the amplitudes of the OAEs per frequency without and with CAS. According to Eggermont,^[39] approximately 79% of the patients with tinnitus inform that tinnitus resembles a tone, whereas 21% claim that it resembles a broadband sound. In the case of OAEs, there is a possible correspondence between the perceived tinnitus tone and the OAEs frequencies, producing abnormally reduced amplitudes or no detectable activity at all. Liu *et al.*^[40] found that in 59% of the patients with normal hearing and tinnitus, the amplitude of the frequencies of the DPOAEs close to the tone of the tinnitus was reduced, and spontaneous acoustic otoemissions were not present. However, in frequencies different to the ones of tinnitus, the DPOAEs amplitude was normal, and the spontaneous acoustic otoemissions could be registered. This interaction has not yet been defined, and it is of interest to analyze the link of the amplitude in the CS of the OAEs and the tone of the tinnitus.

In relation to the suppressive effect, although the difference found between the group without tinnitus and the one with tinnitus was not statistically significant, the observed trend is that the magnitude of the suppressive effect was lower in the group with tinnitus. This constitutes another point of interest to consider and analyze in future studies. Serra *et al.*^[41] found that the TEOAE suppression effects decreased with increasing annoyance of tinnitus in adults with normal hearing thresholds. Mor and de Azevedo^[25] obtained nonstatistically significant difference between the groups without and with tinnitus in terms of the amplitude response of the TEOAEs and suppressive effect. Besides, researches conducted with CS of DPOAEs found that the functioning of the MOCS was less effective in the patients of the group with tinnitus in comparison with the control

group,^[27,42] being another aspect of great interest for future consideration in upcoming studies.

In this research, the adolescents were 65 males and 12 females. The gender differences in TEOAEs amplitude and suppression of TEOAEs were no significant that is why it was decided to analyze jointly. Zamiri Abdollahi and Lotfi^[43] found that there is a significant gender difference in TEOAEs and TEOAEs suppression in normal hearing adults. The TEOAEs amplitude was significantly greater in females, and TEOAE suppression was significantly greater in males. Other study by Durante and Carvallo^[44] has shown gender influence on OAEs and contralateral suppression of OAEs in neonates. They have shown that TEOAEs were larger in female infants, and suppression of TEOAEs was larger in male infants. For this reason, it is necessary to continue research on gender and suppression of TEOAEs in people with tinnitus. It is necessary to include in the literature the results of different populations such as Latin America, mainly South America.

The results of the present investigation provide a contribution to the hypothesis of “the participation of the MOCS,”^[18,19] by showing that the presence of tinnitus was related to a minor functioning of the MOCS, and given the fact that this hypothesis is founded in the idea that the MOCS may produce an alteration in the modulation of outer hair cells and, thus, provoke an imbalance between hyperpolarization and depolarization, generating an electric abnormal and exaggerated activity that is misinterpreted by the central nervous system as a sound.^[18-20] Another contribution, proposed by Lalaki *et al.*,^[45] states that in the generation of noise-induced tinnitus, the MOCS plays an important role, because the abnormal activity of it could indicate its deterioration, or it could as well be due to the outer hair cells responding abnormally to the stimulation of the MOCS. A combination of these two mechanisms cannot be excluded.

In general, the bibliography shows that some researches about the MOCS have been performed with designs that use different application parameters, diverse quantification way of the suppressive effect, and varied criteria for considering OAEs as normal. This lack of united criterion to perform the measurement procedure and the evaluation of the results is a real difficulty for comparisons. At this point, it is important to note what Dhar and Hall^[1] mentioned in relation to the differentiation of the “normal OAEs,” which are referred to as amplitudes consistently inside a required region, and the “present OAEs,” referred to as OAEs amplitudes that are 6 dB above background noise, but still below normal limits. It is unlikely to find people with tinnitus and normal OAEs, but it is highly frequent to find people with tinnitus and present but abnormal OAEs.^[1]

The existence of tinnitus as a symptom is well known; however, a cure does not exist due its unknown origin or causes. It will be difficult for treatments to be successful until the origin of tinnitus can be determined. This highlights the

importance of being able to establish the cause for tinnitus to provide a successful treatment that alleviates or eradicates the symptom, which will affect the quality of life of those who suffer from it. It is important to continue with studies, like the present article, that analyze the suppressor effect and the presence of tinnitus.

Overall, the need to continue doing research in this area to know the scopes of the CS of the TEOAEs for its diagnostic value in audiological tests and their contribution to determine the relationship between the presence and absence of tinnitus and function of the MOCS is evident. To make progress in this area of knowledge may provide the necessary tools for a more accurate diagnosis and, thus, for more efficient treatments allowing to improve the quality of life of those who suffer from tinnitus.

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Conflicts of interest

There are no conflicts of interest.

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