Review Article

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Evoked otoacoustic emissions in workers exposed to noise: A review

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Summary

Introduction: The otoacoustic emissions test is an essential tool in the evaluation of auditory function, since it allows the early detection of cochlear damage of occupational origin.
Objective: To present a review of the literature and analyze the effectiveness of the clinical application of the otoacoustic emissions test in workers exposed to noise.
Methods: A bibliographical search covering a period of 10 years was performed in the Virtual Health Library including published articles in national and international journals indexed in the internationally recognized databases for the health sciences, LILACS, SCIELO, and MEDLINE, using the terms "otoacoustic emissions" and "occupational exposure." The type of published article (national/international), the type and intensity of the stimulus most commonly used for the evoked otoacoustic emissions, the gender and age of the subjects, and the conclusions from the retrospective studies were all taken into consideration.
Results and Conclusions: A total of 19 articles were analyzed, 7 national and 12 international, covering subjects from 17 to 77 years of age, mostly men. The type of stimulus most commonly used for the evoked otoacoustic emissions was the distortion method (12). Through this review, we have concluded that testing of evoked otoacoustic emissions in workers exposed to noise is an important tool in the early diagnosis of noise-induced cochlear hearing disorders.
Keywords: occupational health; hearing; electrophysiology; noise effects; occupational exposure.

Introduction

Hearing is crucial in the communication process, and any change in auditory perception can lead to problems in communication and socialization of human beings with their peers (1,2).

Exposure to loud noise is an occupational health risk factor, causing general, and auditory disturbances (3,4). In the auditory system, noise will affect mainly the outer hair cells in the cochlea.

Current knowledge of the physiology of hearing aids, particularly in the functioning of the cochlea, allows for insight regarding studies of noise-induced hearing loss (NIHL).

It has been reported (5) that noise can affect cochlear function through 7 possible mechanisms: 1. by direct mechanical injury, 2. by excess glutamate in the synapses of inner hair cells, 3. by over-stimulation of *N*-methyl-D-aspartame receptors that would lead to the release of nitric oxide, 4. by free radicals of oxygen atoms, 5. by a reduction of magnesium that would alter intracellular activity, 6. by an increase of intracellular calcium, and 7. by protein damage.

NIHL is irreversible and progressive sensorineural cochlear damage. In the early stages of NIHL, the individual may have tinnitus and a fleeting feeling of auditory plenitude, but the hearing loss cannot be identified in an audiogram. However, with continued exposure to loud noise over several years, there will be hearing loss that can be described in an audiogram, initiating then a permanent decline in hearing (6).

It has also been reported (7) that cell damage by noise can be described in 3 stages, in accordance with exposure time:

1. onset, the death of hair cells with formation of scabs, which is not distinguishable by conventional audiometry; 2. after several years of exposure, damage in the first third of the cochlea, or 10 mm from the cochlear base, which is a more sensitive area owing to metabolic, vascular, and anatomical factors, with detectable changes in audiometric pure tone thresholds of 3–6 kHz; 3. after decades of exposure, injuries of a more extensive range in the cochlea, affecting the mid and low frequencies.

Legally, the evaluation of patients with NIHL occurs through the use of audiometric tests (8). Currently, other objective tests are recommended for early diagnosis of NIHL, as in the case of evoked otoacoustic emissions (EOAE) (9,10,11,12).

EOAE testing was introduced at the end of the 1970s (13), and reduction in the amplitude of EOAE intensity response in patients with NIHL compared to the unexposed group was demonstrated.

Recent research shows that the EOAE test has become an essential tool in the evaluation of auditory function because it allows early detection of cochlear damage resulting from occupational noise (14).

The aim of this study was to analyze the recent scientific literature on the clinical application EOAE tests in workers exposed to noise.

Methods

The universe of analysis chosen for the literature review included scientific publications in national and international journals that were indexed in 3 internationally recognized databases for the health sciences: LILACS, SciELO, and Medline. A search was performed in the Virtual Health Library, covering a period of 10 years, using the terms "otoacoustic emissions" and "occupational exposure."

A survey of the publications was initially performed by reading abstracts in the BIREME virtual library (www.bireme.br), and when the abstract served the interests of this study, the full text of the article was requested for analysis.

The indexed periodicals surveyed in the databases included for this review were national and international scientific publications published in Portuguese or English between 2000 and 2010.

There were 19 papers selected for analysis, 7 national and 12 international. Only 1 study was excluded because its subject of research was animals exposed to broadband noise.

Review

After selection and full analysis of the publications, each article was classified according to whether it was nationally or internationally published, and the articles were indexed by 5 categories: database, article title, author, year, and country of publication.

Next, we analyzed the criteria used by the authors of each article, taking into account the following variables: number of participants, age (given by the variance or mean age), and gender.

Finally, analyses were made of the parameters used in the investigation of the EOAE tests, classifying them by stimulus intensity and type of test: transient evoked, distortion product, or both.

Chart 1 presents the studies classified according to their origin (national/international), database, title, author, year, and country of publication.

Table 1 presents the criteria of the research, taking into account the age (given by the variance or mean age), gender, and number of subjects.

Table 2 shows the analysis of parameters used to investigate the OAEs according to the type of test: transient evoked (TEOAE), distortion product (DPOAE)(11; 57.89%), or both (8, 42.11%), and the intensity of the stimulus.

Results

The goal of this review was to analyze the scientific literature on the clinical application of EOAE tests for workers exposed to noise.

In referring to the origin of publications, there were more articles found in international journals than in national journals (Chart 1).

The results the analysis suggest that EOAE testing ~~is~~ a valuable tool for occupational health research and early diagnosis of NIHL in various professions.

The occupational categories included were: musicians (15,16,17), fishermen (18), farmers (12), construction workers (19,20), military personnel (21), textile industry workers (22), workers in various industrial activities (23,24,25,26,27), university employees exposed

Chart 1. Analysis of scientific articles regarding otoacoustic emissions in workers exposed to occupational noise based on database, article title, author, and year/country.

T	Database	Article Title	Author	Year/Country
National				
1	LILACS	Estudo da audição de músicos de *rock and roll*	Maia and Russo (16)	2008/Brasil
2	LILACS	Exposição ao ruído ocupacional: alteração no exame de emissões otoacústicas	Marques and Costa (4)	2006/Brasil
3	LILACS	Emissões otoacústicas - produto de distorção em indivíduos expostos ao chumbo e ao ruído	Alvarenga et al. (23)	2003/Brasil
4	LILACS	Avaliação Audiológica e de emissões otoacústicas em indivíduos expostos a ruído e praguicida	Guida et al. (12)	2009/Brasil
5	LILACS	Alterações auditivas da exposição ocupacional em músicos	Amorin et al. (15)	2008/Brasil
6	LILACS	Emissões otoacústicas – Produto de distorção: Estudo de diferentes relações de níveis sonoros no teste em indivíduos com e sem perdas auditivas	Fiorini and Parrado-Moran (22)	2005/Brasil
7	LILACS	Aplicações clínicas das emissões otoacústicas: produto de distorção em indivíduos com perda auditiva induzida por ruído ocupacional	Parrado-Moran and Fiorini (31)	2003/Brasil
International				
8	Medline	Audiological findings among workers from Brazilian small-scale fisheries	Paini et al. (18)	2009/USA
9	Medline	Audiological findings in workers exposed to styrene alone or in concert with noise	Johnson et al. (24)	2006/England
10	Medline	Distortion product otoacoustic emissions in an industrial setting	Korres et al. (25)	2009/England
11	Medline	Effect of exposure to a mixture of solvents and noise on hearing and balance in aircraft maintenance workers	Prasher et al. (28)	2005/England
12	Medline	Effectiveness of hearing protector devices in impulse noise verified with transiently evoked and distortion product otoacoustic emissions	Bockstael et al. (21)	2008/USA
13	Medline	Low-level otoacoustic emissions may predict susceptibility to noise-induced hearing loss	Lapsley Miller et al. (29)	2006/USA
14	Medline	Music exposure and audiological findings in Brazilian disc jockeys	Santos et al. (17)	2007/USA
15	Medline	Otoacoustic emission sensitivity to low levels of noise-induced hearing loss	Sisto et al. (26)	2007/USA
16	Medline	Predictions of hearing threshold levels and Distortion product otoacoustic emissions among noise exposed young adults	Seixas et al. (19)	2004/England
17	Medline	Prospective noise induced changes to hearing among construction industry apprentices	Seixas et al. (20)	2005/England
18	Medline	Susceptibility to tinnitus revealed at 2 kHz range by bilateral lower DPOAEs in normal hearing subjects with noise exposure	Job, Raynal, and Kossowski (30)	2007/ Switzerland
19	Medline	The evaluation of noise-induced hearing loss with distortion product otoacoustic emissions	Balatsouras (27)	2004/Poland

Legend: DPOAE: distortion product otoacoustic emissions

to occupational noise (4), carpenters (4), aviation employees (28), mariners (29), aviators (30), and workers exposed to noise (31) (Table 1).

Regarding the combined exposure to noise and environmental contaminants (solvents, asphyxiants, metals, and pesticides) (31), it was noted that there is controversy on this subject. While some authors offered significant evidence of effects on EOAE results in workers exposed simultaneously to noise and chemicals compared to workers exposed only to noise (12,24,28), other authors did not agree (23).

For all studies (Table 1), the total number of

Table 1. Analysis of criteria used in the studies according to the number of participants, age group, and gender

Article	Database	Title	Number of Subjects	Age Group	Gender
1	LILACS	Estudo da audição de músicos de *rock and roll*	23	21–38	19 M 4 F
2	LILACS	Exposição ao ruído ocupacional: alteração no exame de emissões otoacústicas	74	Not specified	74 M
3	LILACS	Emissões otoacústicas - produto de distorção em indivíduos expostos ao chumbo e ao ruído	66	34–40	Not specified
4	LILACS	Avaliação Audiológica e de emissões otoacústicas em indivíduos expostos a ruído e praguicida	51	24–57	51 M.
5	LILACS	Alterações auditivas da exposição ocupacional em músicos	30	18–37	27 M 3 F
6	LILACS	Emissões otoacústicas – Produto de distorção: Estudo de diferentes relações de níveis sonoros no teste em indivíduos com e sem perdas auditivas	G1 = 80 G2 = 89	14–46 20–60	66 M 14 F 66 M 4 F
7	LILACS	Aplicações clínicas das emissões otoacústicas: produto de distroção em indivíduos com perda auditiva induzida por ruído ocupacional	89	20 – 60	64 M. 4 F
8	Medline	Audiological findings among workers from Brazilian small-scale fisheries	141	18–77	141 M.
9	Medline	Audiological findings in workers exposed to styrene alone or in concert with noise	313	20–65	278 M 35 F
10	Medline	Distortion product otoacoustic emissions in an industrial setting	139	24–54	86 M 53 F
11	Medline	Effect of exposure to a mixture of solvents and noise on hearing and balance in aircraft maintenance workers	G1=174 G2=153 G3=13 G4=39	G1=47.4 avg. G2=53.3 avg. G3=49.6 avg. G4=47.6 avg.	Not specified
12	Medline	Effectiveness of hearing protector devices in impulse noise verified with transiently evoked and distortion product otoacoustic emissions	55	19–48	55 M
13	Medline	Low-level otoacoustic emissions may predict susceptibility to noise-induced hearing loss	G1=338 G2=28	18–46 20–53	35 F 303 M 8 F 20 M
14	Medline	Music exposure and audiological findings in Brazilian disc jockeys (DJs)	30	17–39	30 M
15	Medline	Otoacoustic emission sensitivity to low levels of noise-induced hearing loss	217	18–35	Not specified
16	Medline	Predictors of hearing threshold levels and distortion product otoacoustic emissions among noise exposed young adults	436	17–57	367 M 69 F
17	Medline	Prospective noise induced changes to hearing among construction industry apprentices	328	27.5 avg.	272 M 56 F
18	Medline	Susceptibility to tinnitus revealed at 2 kHz range by bilateral lower DPOAEs in normal hearing subjects with noise exposure	316	25–35	306 M 10 F
19	Medline	The evaluation of noise-induced hearing loss with distortion product otoacoustic emissions	34	29–54	22 M 12 F

Legend: M, male; F, female; G 1, 2, 3, 4, groups; avg., average; DPOAEs, distortion product otoacoustic emissions.

Table 2. Analysis of scientific articles in relation to the research parameters used.

Article	Database	Author	Year/Country	Type of OAE	Stimulus Intensity
1	LILACS	Maia and Russo (16)	2008/Brazil	TEOAE	80 dB SPL
				DPOAE	L1 = 65 dB SPL, L2 = 55 dB SPL
2	LILACS	Marques and Costa (4)	2006/Brazil	DPOAE	L1 and L2 intensity not specified
3	LILACS	Alvarenga et al. (23)	2003/Brazil	DPOAE	L1 = 70 dB, L2 = 70 dB
4	LILACS	Guida et al. (12)	2009/Brazil	DPOAE	L1 = 65 dB SPL, L2 = 55 dB SPL
5	LILACS	Amorin et al. (15)	2008/Brazil	TEOAE	79–83 dB SPL
				DPOAE	L1 = 65 dB SPL, L2 = 55 dB SPL
6	LILACS	Fiorini and Parrado-Moran (22)	2005/Brazil	DPOAE	L1 and L2 = 70 dB SPL; L1=65 dB SPL, L2=55 dB SPL
7	LILACS	Parrado-Moran and Fiorini (31)	2003/Brazil	DPOAE	L1=65 dB SPL, L2=55 dB SPL
8	Medline	Paini et al. (18)	2009/USA		
9	Medline	Johnson et al. (24)	2006/England	DPOAE	L2 = 10 dB below L1, intensity not specified
10	Medline	Korres et al. (25)	2009/England	DPOAE	f1 = 60 dB SPL, f2 = 45 dB SPL
11	Medline	Prasher et al. (28)	2005/England	TEOAE	80 dB SPL
				DPOAE	L1 = 5 dB SPL, L2 = 55 dB SPL
12	Medline	Bockstael et al. (21)	2008/USA	TEOAE	86 dB SPL
				DPOAE	L1 = 75 dB SPL, L2 = 70 dB SPL
13	Medline	Lapsley Miller et al. (29)	2006/USA	TEOAE	74 dB pSPL click
				DPOAE	L1 = 57 dB SPL, L2= 45 dB SPL L1 = 59 dB SPL, L2 = 50 dB SPL L1 = 61 dB SPL, L2 = 55 dB SPL L1 = 65 dB SPL, L2 = 45 dB SPL
14	Medline	Santos et al. (17)	2007/USA	TEOAE	80 dB.
				DPOAE	L1 = 65 dB HL, L2 = 55 dB HL
15	Medline	Sisto et al. (26)	2007/USA	TEOAE	80 dB click
				DPOAE	L1 = 65 dB & L2 = 55 dB L1 = 75 dB & L2 = 70 dB L1 = L2 = 70 dB
16	Medline	Seixas et al. (19)	2004/England	DPOAE	L1 = 65 dB SPL & L2 = 55 dB SPL Also registered regarding rising stimulus level (L1 = 35–80 dB SPL in steps of 5 dB; L2 = L1–10)
17	Medline	Seixas et al. (20)	2005/England	DPOAE	L1 = 65 dB SPL, L2 = 55 dB SPL Also registered regarding rising stimulus level (L1 = 35–80 dB SPL in steps of 5 dB; L2 = L1–10)
18	Medline	Job, Raynal, Kossowski (30)	2007/Switzerland	DPOAE	L1 = 65 dB, L2 = 55 dB
19	Medline	Balatsouras (27)	2004/Poland	DPOAE	L1 = L2 = 70 dB SPL

Legend: OAE, otoacoustic emissions; TEOAE, transient-evoked otoacoustic emissions; DPOAE, distortion product otoacoustic emissions; L1, L2, stimulus intensities; dB SPL and dB HL, decibels in sound pressure level.

individuals evaluated was 3256, with 2246 males, 397 females, and 612 unspecified. The participation of males was greater than that of females, which reflects the overall lower number of women in the professional categories evaluated.

Regarding age, participants ranged from a minimum age of 14 years (22) to a maximum of 77 (18). In the variation of the EOAE findings, 1 study showed that the greater the subject's age, the greater the increase in tonal thresholds, while DPOAE thresholds decrease (19). In this study, which divided the subjects into 4 age groups (age, up to 20 years, 20–29 years, 30–39 years, and over 40 years), it was observed that increasing age significantly influenced ($p > 0.05$) the amplitude of the EOAE.

In relation to the type of test chosen in the studies to investigate EOAE, of the 7 articles that are available in the national LILACS databases, 5 used DPOAE (4,23,12,22,31) and only 2 used both tests (15,16). Of the 12 international papers in the Medline database, 6 used DPOAE (24,25,19,20,27,30) and 6 used both tests (18,28,21,12,29,17,13,26).

It is suggested that DPOAE have characteristics that facilitate a more accurate diagnosis. For example, examiners can perform frequency and variation band analysis of responses depending on stimulus intensity (32). The examiner can vary the intensity, using the protocols L1 = L2 = 70 dB SPL or L1 = 65 dB SPL and L2 = 55 dB SPL (65/55 protocol).

As to the stimulus intensity, in the LILACS database, national articles varied intensities between L1 and L2, with the most frequently used intensity of L1 = 65 dB SPL and L2 = 55 dB SPL (12,15-17,20,22,26,28,30,31). In the Medline database, although the values L1 = 65 dB SPL and L2 = 55 dB SPL were also used (26), there is a wide variation of stimulus intensities (21,23,25-27,29).

Analysis of the DPOAE at different intensities of stimulation must be regarded very carefully, because it is likely that different mechanisms are responsible for the production of increasing or decreasing the sound intensity. Recent research indicates that the largest DPOAE amplitudes are obtained when L1 is more intense than L2 (L1 > L2) by up to 10 dB (33).

The lower intensity stimuli are more sensitive and accurate in the diagnosis of mild and moderate sensorineural hearing loss, which permits the variation of intensity to be used to differentiate degrees of mild and moderate hearing loss. That is, the 65/55 protocol appears to be more sensitive in detecting mild hearing loss.

However, it is noteworthy that the proper adjustment of the probe is essential for recording otoacoustic emissions. As well as being sensitive to noise created by the environment or the patient himself, it is a highly sensitive procedure for disorders of the external ear and middle, thus generating possible false-positives (35). Moreover, the fact is indisputable that this procedure does not exclude the possibility of false-negative result, that is, integrity of cochlear physiology in auditory neuropathy.

In our review, only one study cited the possibility of false-positive and false-negative results, the causal factors that could have been calibration problems, noise level during the test and test-retest variability (29).

Final Comments

In the universe that was analyzed, we observed that EOAE testing has been used effectively in the detection of cochlear changes and the early diagnosis of NIHL.

The literature reviewed publications that established results that can be considered as important parameters for subsequent applications of EOAE in workers exposed to noise.

We suggest that further epidemiological studies should be carried out to analyze the effectiveness of EOAE in workers exposed simultaneously to noise and other environmental contaminants (solvents, asphyxiants, metals, and pesticides), as well efforts towards suppression of the hazards in the occupational area.

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