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Comparative Study of Evoked Otoacoustic Emissions in Offshore and Onshore Seafaring Workers

Estudo comparativo das emissões otoacústicas evocadas em trabalhadores marítimos Offshore e Onshore

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Keywords

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ABSTRACT

Purpose: To evaluate the cochlear function of offshore and onshore seafaring workers of a naval company in the city of Rio de Janeiro and to estimate the degree of association between occupational exposure to noise and/or chemical substances and alteration in cochlear function. **Methods**: This study evaluated seafaring workers aged 20 to 49, of both genders, without auditory symptoms, divided into two groups: the Offshore Group, operating in the high seas with occupational exposure; and the Onshore Group, operating in offices without occupational exposure. Exams were performed to evaluate cochlear function, including transient evoked otoacoustic emissions (TEOAE) and distortion product otoacoustic emissions (DPOAE). **Results**: The TEOAE and DPOAE responses were on average lower in the Offshore Group, for all frequencies analyzed. The proportion of failures observed was also higher in the exposure group (Offshore), for general response and specific frequency, mainly for the frequencies of 4 kHz for TEOAE and 6 kHz for DPOAE. **Conclusion**: The results suggest that exposure to noise and/or chemical substances can contribute to alterations in cochlear function in seafarers even without manifesting auditory symptoms.

Descritores

Células Ciliadas Auditivas
Exposição Ambiental
Ruído
Compostos Químicos
Saúde do Trabalhador

RESUMO

Objetivo: Avaliar a função coclear de trabalhadores marítimos *Offshore* e *Onshore* de uma empresa naval da cidade do Rio de Janeiro e estimar a magnitude de associação entre a exposição ocupacional ao ruído e/ou substâncias químicas e alterações na função coclear. **Método**: Neste estudo, foram avaliados trabalhadores marítimos entre 20-49 anos, de ambos os gêneros, sem queixas auditivas, distribuídos em dois grupos: o Grupo *Offshore,* que operam em alto mar com exposição ocupacional; e o Grupo *Onshore,* que operam em escritórios sem exposição ocupacional. Para avaliação da função coclear, foram realizados os exames de emissões otoacústicas evocadas por estímulo transiente (EOAT) e por produto de distorção (EOAPD). **Resultados**: As respostas das EOAT e EOAPD foram, em média, menores no Grupo *Offshore*, para todas as frequências analisadas. A proporção de falhas observadas também foi maior no grupo de exposição (*Offshore*), tanto no critério geral quanto por frequência específica, principalmente para as frequências mais agudas de cada teste, 4 kHz para EOAT e 6 kHz para EOAPD. **Conclusão**: Os resultados sugerem que a exposição a ruído e/ou a substâncias químicas pode contribuir significativamente para alterações da função coclear de trabalhadores marítimos, mesmo antes de manifestarem queixas auditivas.

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INTRODUCTION

The growth of the oil industry has strengthened the operational sectors in the naval market, emphasizing different types of work, which can be divided into Onshore and Offshore. The main difference between them is the operation environment, "on land" and "at sea", respectively. The containment regime experienced by offshore workers is an important distinguishing feature between these two modalities. This regime exposes them intensely to intrinsic and varied risks due to the diversity of physical and chemical processes inherent to this industrial environment[1]. Thus, the conditions of offshore work can bring many negative consequences, both physical and psychoactive[2]. In this operational context, the hearing health of offshore maritime workers becomes a relevant concern; however, little is explored in the scientific literature. In addition to noise, there are also ototoxic chemical substances, and the coexistence of these risks in the work environment, as occurs in vessels, can potentiate auditory effects due to the synergism, explained by the combination of two or more agents, which can exceed the sum of the damage that each one does[3].

Hearing is a sensory function that promotes social integration of the individual[4]. The interrelation of sensory structures and central connections that constitute the auditory system is fundamental for this function. Understanding this system is essential to grasp how exposure to risks in the occupational environment, such as noise and chemical substances, can compromise specific regions and favor the development of hearing loss with particular audiological characteristics. In the peripheral auditory system, sound is captured and transmitted by the outer and middle ear, until it reaches the inner ear. In the anterior part of the inner ear we find the cochlea, the main organ responsible for hearing. Its nomenclature comes from the Greek *kokhia*, which means snail, for its spiral shape[5]. The main injuries that characterize occupational hearing loss occur in this organ, initially affecting outer hair cells (OHC), followed by damage to inner hair cells (IHC)[6]. This anatomical disposition underlies the interpretation of the audiological exams used in clinical practice.

Pure Tone Audiometry (PTA) is considered the gold standard in the investigation of hearing loss[7] and is consolidated in national legislation as part of the set of procedures necessary for assessment and monitoring of workers' hearing throughout the period of noise exposure. However, despite the undeniable importance of PTA, this examination of a subjective character is capable of detecting hearing loss only when there is already an OHC lesion, which in this case is irreversible. Nevertheless, research has observed that examination of Evoked Otoacoustic Emissions (EOAE) can detect cochlear alterations early, even before identifying the alteration in the audiometry exam[8], since this exam has greater sensitivity to observe functional alterations in the OHC, which are the first to be reached[9]. Evoked otoacoustic emissions have an uptake sensitivity estimated between 85-95%, with specificity greater than or equal to 90%[10]. Monitoring of hearing in workers exposed to noise and chemical substances is among the clinical procedures applied to adult individuals. It is an objective procedure, non-invasive, fast, portable and applicable in places with no acoustic treatment[10].

The importance of acting preventively, that is, even before damage is installed, is unquestionable in the area of workers' health, which proves the relevance of early detection of changes in cochlear function.

However, as mentioned above, hearing of offshore workers is a little-explored topic, especially in Brazilian scientific literature. There are studies in international literature that assess the prevalence of hearing damage related to work in the offshore industry[11,12] and correlate auditory effects with noise exposure in this population[13]. However, the main research focuses on issues of social and psychological import[1,14,15], addressing hearing loss only secondarily. Thus, this study aims to highlight the hearing health of this population, potentially exposed and, therefore, subject to audiological alterations. It contributes to other scientific studies, in an attempt to mitigate some limitations already mentioned[16], such as the need for a control group for better data validation. The objective of this study is to evaluate the cochlear health of offshore and onshore maritime workers from a naval company in the city of Rio de Janeiro and to estimate the magnitude of the association between occupational exposure to noise and/or chemical substances and changes in cochlear function.

METHODS

The study was analyzed and approved by the Research Ethics Committee of Hospital Universitário Clementino Fraga Filho, under number 62731416.5.0000.5257-17. The workers received instructions about the research, agreed to participate and signed an informed consent form. This is a cross-sectional, descriptive, and comparative study between groups, using quantitative analysis. The convenience sample was defined by the number of workers who agreed to participate in the research and were available at the time of collection, which took place between July and October 2019. All participants were from a naval company in the municipality of Rio de Janeiro and were divided into two groups, according to the type of work: The Offshore Group (OFG) and the Onshore Group (ONG). Forty-nine years old was defined as the age limit for inclusion in the study, to minimize the possibility of confusion due to hearing impairment caused by aging, called presbycusis. Table 1 describes the other inclusion and exclusion criteria for the groups. Data collection was performed at the office of the shipping company, taking advantage of the period when offshore workers were preparing for shipment, a stage known as pre-shipment. Therefore, workers had been absent from maritime activity for about 28 days. The onshore workers operated in this same office. Thus, the data collection site was common to both groups. All participants were submitted to a semi-open questionnaire about their clinical-occupational history containing variables such as age, gender, function, exposure, time of exposure, use of Personal Protective Equipment (PPE) and hearing complaints; inspection of the external auditory canal, through otoscopy; transient-evoked otoacoustic emissions by stimulus (TEOE) and by distortion-product otoacoustic emissions (DPOAE).

The researchers explained the clinical-occupational questionnaire and subsequently they were self-completed by each study

Table 1. Inclusion and exclusion criteria for the study

Criterion		Offshore Group	Onshore Group
Inclusion	Both genders	✓	✓
	Age between 20 and 49 years;	✓	✓
	Report good audibility in both ears;	✓	✓
	Normal otoscopy;	✓	✓
	Being an offshore worker exposed to noise and/or chemicals in the workplace;	✓	✗
	Being an onshore worker with no current or previous occupational exposure to noise and/or chemicals;	✗	✓
	Minimum time in current position equivalent to one year.	✓	✓
Exclusion	Alteration of the external and/or middle ear; history of ear surgery.	✓	✓
	Report of use of ototoxic medication;	✓	✓
	Report of acoustic trauma;	✓	✓
	History of neurological, metabolic, or genetic diseases;	✓	✓
	History of measles, mumps, or meningitis;	✓	✓
	Hearing loss history;	✓	✓
	History of exposure to loud noise and/or ototoxic chemicals in an extra-occupational environment or previous function*.	✓	✓

*For seafarers in the Offshore group, workers with a history of exposure to loud noise and/or chemical substances in previous jobs that were also offshore were not considered for exclusion

participant to minimize examiners' bias. However, at the end the examiner checked the completed questionnaire and, in case of doubts or unanswered information, these were highlighted so that the participant could fill them out. We performed otoscopy using the Mikatos Led Mini 1000 instrument. Workers with changes in otoscopy were instructed and referred for otorhinolaryngologic evaluation and excluded from the sample. The TEOE and DPOAE measurements were performed in an isolated room, extremely quiet and with a minimum level of noise, where each participant was assessed separately. All workers received prior guidance prescribing a minimum of 14 hours of auditory rest. No maritime worker performed diving activities before the exams.

Answers were captured in both ears, alternately, starting with the right ear through an olive adapted to the probe of the ILO288 Otodynamics equipment. We considered the following parameters for each test:

- TEOE: We used a broadband click stimulus, non-linear, frequency from 1500 Hertz (Hz) to 4000 Hz, at an intensity of 84 Sound Pressure Level (SPL) and probe stability greater than 70%. Answers were considered present when general reproducibility was greater than 50% with an answer amplitude of the signal/noise ratio greater than or equal to 3 dB ($Y/N \geq 3dB$), in at least three consecutive frequencies evaluated[17]. Answers obtained within the aforementioned criteria were considered as "approved", and the exams different from those were classified as "failing";
- DPOAE: Two primary pure tones were presented simultaneously, with different frequencies (f1 and f2) at the f1/f2 = 1.22 ratio, in two-octave points; and at intensities of 65 and 55dBNPS, for f1 and f2, respectively. We analyzed the responses at frequencies ranging from 1500 Hz to 6000 Hz. Depigran's response (2f1-f2) was considered present when the response level of the signal/noise ratio was equal to or greater than 6 dB ($S/N \geq 6dB$) in at least three frequencies tested, determining the presence - "approved" - or absence - "failure" - of cochlear responses[17].

In addition to the general criterion, we also considered for the analysis the S/N ratio by specific frequency and the duration of each exam (measured in seconds). The 1000 Hz frequency was not analyzed in any of the tests described, as it showed changes in the reproducibility and amplitude of the S/N ratio.

We stored the collected data in Excel spreadsheets and then imported the data into the SPSS (Statistical Package for the Social Sciences) software for statistical analysis. Initially, descriptive analyzes of the collected variables were performed. Subsequently, we tested the normality of the distributions, using the Mann-Whitney Tests for samples that were not normal and Student's T-Test for samples with a normal distribution. Finally, Pearson's Chi-square test analyzed the proportion of failures of the S/N ratio by specific frequency and by general criterion in TEOE and DPOAE, in each ear, and by group. For statistical significance, we accepted $p < 0.05$.

RESULTS

The study included 85 adult workers between 20 and 49 years old, of both genders. The Onshore Group (ONG) included 37 individuals who worked at offices with a workload of 8 hours per day, and the Offshore Group (OFG) comprised 48 individuals who worked on board with a daily workload of 12 hours in 28 x 28 shifts, that is, 28 days operating on the high seas and 28 days of rest on land. The prevalence in the ONG was female (69%) while the OFG had a prevalence of males (85%). Regarding the Offshore workers' workplace on the vessel, 18.8% worked on the deck, 18.8% on the superstructure, 29.2% on the walkway, and 33.3% in the engine room. The OFG had an average of 5.3 years in the current function and a standard deviation (SD) equal to 4.7, while the ONG had an average equivalent to 2.5 (SD = 2.5). Offshore workers were the group exposed to environmental risks, such as physical (noise) and/or involving chemicals, inherent to the shipbuilding industry. Thus, the OFG was characterized by exposure to noise and chemical substances, as described in Table 2.

Table 2. Main characteristics of the Offshore Group regarding exposure to noise, time of exposure to noise, exposure to chemical substances, type, and time of exposure to chemical substances. Rio de Janeiro, 2019

Variable	Category	*Offshore Group*	
		N	%
Exposure to noise	Yes	48	100
	No	0	0
Exposure time to noise	≤10 years	28	58.3
	>10 years	20	41.7
Exposure to chemical subst.	Yes	39	81.3
	No	9	18.8
Chemical exposure type	Not exposed	9	18.8
	Cleaning prod.	7	14.6
	Solvents, cleaning agents prod., oils and greases	16	33.3
	Solvents, cleaning agents prod., oils, greases, and vapors	16	33.3
Exposure time to chemical subst.	≤10 years	30	76.9
	>10 years	9	23.1

Caption: N = Number of workers

Table 3. Average, median, minimum/maximum, and standard deviation of duration, in seconds, for capturing TEOAE and DPOAE, and the number of frequencies "approved" in RE and IE, per group. Rio de Janeiro, 2019

Variable	Group	Mean	Median	Minimum	Maximum	Standard Deviation	p-value
Duration	*Offshore*	50.4	60.5	9	124	29.5	0.000*
TEOE RE	*Onshore*	25.5	14	9	70	19.5	
Duration	*Offshore*	53.3	64.5	6	184	31.5	0.002*
TEOE LE	*Onshore*	35.5	24	9	161	33.2	
Duration	*Offshore*	48.6	35.5	19	183	35.3	0.001*
DPOAE RE	*Onshore*	31.7	19	19	132	25.7	
Duration	*Offshore*	52.8	44.5	19	144	34.7	0.003*
DPOAE LE	*Onshore*	33.7	19	19	132	26.7	
Number of frequencies that approved	*Offshore*	2.6	3	0	4	1.3	0.001*
TEOE RE	*Onshore*	3.7	4	2	4	0.7	
Number of frequencies that approved	*Offshore*	2.8	3	0	4	1.4	0.009*
TEOE LE	*Onshore*	3.6	4	0	4	1.2	
Number of frequencies that approved	*Offshore*	2.8	3	0	5	1.4	0.000*
DPOAE RE	*Onshore*	4.6	5	2	5	1	
Number of frequencies that approved	*Offshore*	2.7	3	0	5	1.6	0.000*
DPOAE LE	*Onshore*	4.1	4	0	5	1.4	

Statistical method: Mann-Whitney test; *P value <0.05: statistical significance;
Caption: TEOE = transient evoked otoacoustic emission; DPOAE = distortion product evoked otoacoustic emission; RE = right ear; LE = left ear

To analyze the average exposure time of the OFG, we considered exposure in the current function and in previous functions performed only on vessels, excluding workers who reported exposure to noise and/or chemical substances in any previous function other than offshore, as described in Table 1. Thus, the average time of noise exposure in the OFG was 11.7 hours per day (SD = 1.4). Regarding time of exposure, the average was 9.2 years (SD = 6.6). When analyzing chemical exposure, these values decrease to an average of 4.2 hours (SD = 3.48) and 5.0 years (SD = 5.4). As for the use of PPE for hearing, we observed that all individuals in the OFG used some type, such as plug, shell, or plug associated with the shell. On the other hand, as the ONG is not exposed to high sound pressure levels, no worker mentioned use of protection. OFG members also referred to the use of other types of PPE, in addition to hearing aids, such as boots, gloves, overalls, helmets, and goggles.

Regarding otoacoustic emissions, we set some parameters as variables for comparison between the groups: duration of the exam, several frequencies that passed each test, an average of the S/N ratio by specific frequency, and the "approval/failure" criterion. The Mann-Whitney test showed with statistical significance ($p < 0.05$) that, on average, individuals from the OFG had a duration of the TEOE and DPOAE tests, both for the right and the left ear, higher than those of the ONG. Regarding the number of approved frequencies, we observed more answers in the ONG for the same statistical test, with significance, both for TEOE and for DPOAE in both ears (Table 3).

Table 4 describes the values of the mean, median, standard deviation, minimum/maximum of the S/N ratio, by frequency, obtained by the group and by ear for the TEOE and DPOAE tests. The S/R ratio in the TEOE tests and DPOAE were, on average, lower in the OFG for all frequencies analyzed. When analyzing whether these differences were statistically significant, the 4 kHz frequency in both ears stands out in the TEOE, in addition to the 1.5 kHz frequency only for the right ear, AND the 3 kHz frequency showed a tendency for significance in both ears. As for DPOAE, all results analyzed showed statistically significant differences.

Finally, when analyzing the percentage distribution of the S/N ratio considering the "approval/failure" criterion, the OFG had the highest percentage of failure in the TEOE and DPOAE exams by specific frequency and by general result in both ears (Table 5). The highest proportion of failures was also notorious for the highest frequencies of each test, 4 kHz for TEOE and 6 kHz for DPOAD. When performing Pearson's Chi-square statistical method, we observed statistical significance for TEOE in the 3 kHz and 4 kHz frequencies in the right ear and in the 1.5 kHz, 4 kHz, and 6 kHz (right ear) and 6 kHz (left ear) frequencies for the DPOAE test, in addition to the significance of the general "approval/failure" criterion in both ears.

Table 4. Mean, median, standard deviation, minimum/maximum Signal/Noise ratio, by specific frequency, by ear and by group, in the TEOE and DPOAE test. Rio de Janeiro, 2019

TEOE RE	*Offshore* group					*Onshore* group					p-value
	Mean	Median	SD	Min.	Max.	Mean	Median	SD	Min.	Max.	
1.5 kHz	2.8	3.8	5.6	-11.0	14.2	6.7	7.2	5.0	-3.2	17.9	0.002[1]*
2.0 kHz	7.0	7.0	6.6	-15.7	16.0	8.9	9.6	4.3	0.2	17.7	0.126[2]
3.0 kHz	4.3	5.1	6.6	-14.5	18.8	6.8	6.6	4.1	-3.8	15.8	0.055[1]
4.0 kHz	2.2	2.0	5.7	-9.0	14.0	5.9	6.0	4.4	-3.3	17.1	0.004[1]*
TEOE LE											
1.5 kHz	3.9	4.5	5.0	-11.0	12.2	4.6	6.9	6.5	-14.5	18.9	0.327[1]
2.0 kHz	5.7	6.8	7.2	-15.7	19.9	8.3	8.8	4.5	-2.1	19.4	0.091[1]
3.0 kHz	4.2	5.7	5.3	-14.9	14.6	6.1	6.5	5.0	-13.0	13.7	0.076[1]
4.0 kHz	1.8	3.1	5.7	-9.4	10.2	4.8	6.1	5.0	-5.3	18.3	0.033[1]*
DPOAE RE											
1.5 kHz	4.0	4.3	8.1	-12.0	23.0	9.3	9.5	5.8	-3.2	19.5	0.001[2]*
2.0 kHz	5.4	6.8	7.8	-18.2	19.3	9.6	9.5	5.3	-1.7	22.0	0.010[1]*
3.0 kHz	5.6	7.0	8.7	-15.0	21.5	10.2	11.5	8.2	-13.2	23.0	0.008[1]*
4.0 kHz	6.5	8.2	9.3	-16.6	23.1	12.2	15.2	7.2	-16.7	26.0	0.000[1]*
6.0 kHz	5.6	5.8	7.6	-11.0	26.0	13.1	12.9	7.0	-7.0	27.0	0.000[2]*
DPOAE LE											
1.5 kHz	3.3	4.2	7.7	-11.3	14.6	6.7	7.3	7.0	-7.9	19.0	0.044[2]*
2.0 kHz	4.6	7.3	8.1	-18.0	19.5	9.3	10.3	7.2	-7.8	20.6	0.004[1]*
3.0 kHz	5.1	7.2	7.7	-15.3	21.6	8.3	10.0	10.6	-16.0	22.0	0.002[1]*
4.0 kHz	5.9	7.5	9.7	-15.0	22.3	13.8	15.2	7.7	-8.7	26.0	0.000[1]*
6.0 kHz	5.9	5.7	6.6	-7.0	28.8	13.2	13.4	7.1	-6.0	29.6	0.000[1]*

Statistical method: [1]Mann-Whitney test, [2]T de *Student test;* *P value <0.05: statistical significance;
Caption: TEOE = transient evoked otoacoustic emission; DPOAE = distortion product evoked otoacoustic emission; RE = right ear; LE = left ear; SD = standard deviation

Table 5. Percentage of failure considering the Signal/Noise ratio by specific frequency and by general criterion in TEOE and DPOAE, subdivided by groups and by ear. Rio de Janeiro, 2019

	Right ear		Left ear		p-value	
	% Failures		% Failures			
	Group *Offshore*	Group *Onshore*	Group *Offshore*	Group *Onshore*	RE	LE
TEOE						
1.5 kHz	41.7	21.7	37.5	27.1	0.051	0.308
2.0 kHz	23.0	13.5	27.0	10.9	0.272	0.063
3.0 kHz	37.5	16.3	35.5	19.0	0.031*	0.094
4.0 kHz	54.2	19.0	48.0	32.0	0.001*	0.150
Geral	37.5	2.7	27.1	10.9	0.196	0.063
DPOAE						
1.5 KHz	50.1	21.8	49.0	37.9	0.007*	0.353
2.0 kHz	40.0	21.7	41.7	27.1	0.078	0.161
3.0 kHz	37.5	19.0	43.7	13.6	0.062	0.003*
4.0 kHz	37.5	8.0	39.6	10.9	0.002*	0.003*
6.0 kHz	54.2	8.0	52.1	13.6	0.000*	0.000*
General	29.2	5.3	35.5	10.9	0.005*	0.009*

Statistical method: Quiquadrado de *Pearson* test; *P value <0.05: statistical significance;
Caption: TEOE = transient evoked otoacoustic emission; DPOAE = distortion product evoked otoacoustic emission; RE = right ear; LE = left ear

DISCUSSION

Offshore maritime work is said to be peculiar due to its technological characteristics, human resources, its imminent link to occupational risks and the confinement regime under which the worker remains in the workplace for several consecutive days even at times of rest and leisure[18]. Thus, according to the function in which they perform on the high seas, workers are exposed to bad weather that affects their health and safety and can lead to accidents or illnesses at work[19].The naval company involved in this study presents exposure to several environmental risks in its operational processes on the high seas, such as physical (including noise) and chemical hazards. Changes in cochlear function can occur due to prolonged and excessive exposure, not only to noise but also to chemicals. The combined exposure of these agents can potentiate auditory effects[3]. Studies have observed that examination of evoked otoacoustic emissions can detect hearing alterations early, even before they show up in the pure tone audiometry exam[8].

Kemp defined otoacoustic emissions (OAE) as the release of sound energy emitted by the OHC in the cochlea, which propagates in the middle ear until it reaches the external auditory canal[20]. OAEs can be divided into spontaneous and evoked. Evoked OAEs of the transient type and produced by distortion, used in this study, have the best clinical applicability. Research has shown that the early stages in most sensory hearing loss cases are associated with cochlear mechanical response. Thus, it has become possible to use evoked otoacoustic emissions (EOAE) to monitor cochlear physiology during exposure to various ototoxic agents and also to noise[21]. However, even so, EOAE is not used in the clinical routine of hearing conservation programs for workers exposed to noise, with pure tone audiometry being the universally adopted method. A study highlights that audiometry may not be the best means of assessing disturbances produced by noise, as it is an error-prone test for being a subjective exam (depending directly on responses from the individual under assessment) and points out that another disadvantage is its low sensitivity to detect the subtle cochlear changes that occur before hearing loss shows up in the audiogram[22]. Thus, this study evaluated cochlear function in seafarers without hearing complaints using evoked otoacoustic emissions. For the selection of individuals it should be said that, regarding audibility, we could not consider pure tone audiometry tests and immittance testing, although this had been the researchers' initial intention. The reason is that only the group with exposure to noise (Offshore) had auditory monitoring by the company for which they worked, and, for logistical and operational reasons, we could not carry them out on all workers of the onshore group with the required standardization. However, none of the workers included in this study reported hearing loss in previous exams or had any complaints regarding audibility.

Even so, the workers exposed to occupational risks (Offshore group), who had no hearing complaints, presented worse responses in the TEOE and DPOAE exams than the unexposed group (Onshore) regarding several parameters analyzed, indicating possible changes in their cochlear function, as observed in the literature[23].

Regarding the average duration of each exam in seconds for TEOE and DPOAE, we observed longer times in the offshore group (Table 3). This may be related to a possible decrease in the number of outer hair cells in the cochlea, which hinders the capture of evoked otoacoustic emissions and consequently increases the duration of each test. The average number of frequencies approved was higher for the onshore group (Table 3). These findings suggest, with statistical significance, that offshore workers have more altered frequencies in the evoked otoacoustic emission tests and greater difficulty in recording these answers.

Quantitative analysis of the S/N ratio by specific frequency was on average lower in the offshore group than in the onshore group, both for TEOE and DPOAE (Table 4). When analyzing the "approval/failure" criterion, the offshore group had the highest percentages of failure by specific frequency and general result in both ears (Table 5). These findings corroborate other studies that indicate lower responses of the S/N ratio and greater failures in transient otoacoustic emissions and by product distortion when individuals are exposed to high noise[6,24].

In this study, the proportion of failures was greater in the higher frequencies of each test, with 4 kHz for TEOE and 6 kHz for DPOAE (Table 5). This observation converges with the literature[23] showing that hearing impairment due to occupational exposure starts with high frequencies, as the cochlear region is initially affected and more sensitive. However, if the exposure does not cease, it can reach other frequencies, in the medium and low ranges, generally in that order. We also found statistical significance for TEOE in the 3 kHz and 4 kHz frequencies in the right ear; and at the 1.5 kHz, 4 kHz and 6 kHz (right ear) and 3 kHz, 4 kHz and 6 kHz (left ear) frequencies for the DPOAE test, in addition to significance in the general criterion of "approval/failure" in both ears (Table 5). Another study[22] also found statistical significance at the 1500 Hz frequency in the right ear; however, it attributed this finding to a variation of the volunteer or the device.

A cross-sectional study, Marques et al[23], compared DPOAE in two groups of individuals, exposed and not exposed to occupational noise, with pure normal thresholds. As a result, they identified a correlation between exposure to occupational noise and absence of responses in the DPOAE. The Odds Ratio results for absent responses (failure) in the recording of DPOAE were higher for workers exposed to occupational noise, especially in high frequencies, as occurred in this study.

As we have already mentioned, in addition to noise, chemical substances can also cause changes in cochlear function. Chemicals are exogenous ototoxic factors likely to induce ototoxic hearing loss in workers from different occupational segments, and, when combined with noise, can heighten hearing damage[16]. Solvents are among the main ototoxic chemical substances described in the literature[25,26]. A comparative study analyzed audiometric exams in 155 metallurgical workers split between the group exposed to noise (group I) and that exposed to noise and chemicals (group II); it concluded that group II had a proportionally higher prevalence of hearing loss when compared to group I, even though they had been exposed to aggressor agents for a shorter average time[27].

In this study, all workers in the offshore group were exposed to noise and 81.2% were also exposed to some type of chemical substance. Of this total, 82% were exposed to a solvent combined with some other type of chemical substance, as shown in Table 2. A systematic review study which analyzed 31 articles evaluating the hearing of individuals exposed to chemicals highlighted that the data on the association of both factors showed statistically significant values for “exposure to solvents” and “hearing damage”, with a greater chance of developing hearing loss when exposure to solvents was associated with noise(16). There was also an association between exposure to chemical substances and dysfunction in the central auditory pathway, which may extend from the auditory nerve (VIII cranial nerve pair), brain stem to the cerebral cortex. In this same article, the prevalent choice for cross-sectional studies and the absence of a control group, with no exposure, were highlighted as some of the limitations that could impair the quality of the analysis(16). Thus, in this study, we have defined a group with no exposure, consisting of onshore workers - not exposed in their work environment to loud noise and/or chemical substances.

Another study evaluated audiometric data on co-exposure to noise and a mixture of organic solvents in 701 shipyard workers; 517 exposed to noise and a mix of organic solvents, 184 only to noise, and 205 workers not exposed to any noise or solvents, used as a control group. The chance of hearing loss was significantly increased by a factor of approximately 3 times in the group exposed to noise only, and by almost 5 times in the group exposed to both noise and solvents. A moderate effect of solvent ototoxicity and noise was observed at the auditory threshold at the frequency of 8 kHz(28). The same trend was seen in another study that aimed to assess the effects of occupational exposure to solvents only or in combination with hearing noise in 1117 employees in the yacht, ship, plastic, shoe, paint, and lacquer industries(25), in which the chances of developing hearing loss increased substantially in the case of combined exposure to both organic solvents and noise, compared to isolated exposure to each of these hazards, with a positive linear relationship between exposure to solvents and hearing thresholds at high frequencies(25).

Sisto et al.(29) evaluated recently the sensitivity of distortion product otoacoustic emissions for different solvents and noise in a population of 17 painters from a shipbuilding industry. They concluded that DPOAEs are sensitive biomarkers of exposure to ototoxic substances and can be effectively used for early detection of hearing impairment.

The office was the only place of the group of onshore workers (a requirement for choosing this population as a comparison group). In the offshore group, the problem varied between the various locations of the vessel, with prevalence for the engine room (33.3%). This environment presents the greatest exposure to noise since the ship’s propulsion engines, besides the central air conditioning and electricity supply, are located there. A survey of 149 Thai naval officers highlighted that the noise level in the engine room reached 100.6 dB, and found that 39.6% of naval officers had hearing loss. Thus, these authors concluded by suggesting that the Thai navy should develop a hearing conservation program for naval officers in coastal patrol craft(11). Such a hearing conservation program would seek to minimize risks arising from hearing exposure through measures adopted by the employer, such as replacement or maintenance of equipment causing a lot of noise exposure, instructions on the correct use of machinery, technical measures (shielding, noise absorption) or organizational steps to shorten the duration and intensity of exposure. If these measures are not sufficient to avoid the risk, the employer must provide personal protective equipment and perform audiometric monitoring.

We observed the use of PPE for hearing in all individuals in the OFG. Use of PPE is a measure mandated by Brazilian legislation to protect hearing against the effects of noise. However, according to Azevedo *et al.*, even employees using PPEs may present occupational hearing loss, mainly in the 3 to 6 kHz frequencies, which may be related to incorrect use of this equipment(30). Thus, in addition to providing PPE, employers need to carry out training and inspection on their use. Information about the magnitude and characteristics of auditory effects produced by continuous exposure to chemical substances and the possible interactions, routes of introduction, quantity, and time of exposure without known damage to hearing health, although much discussed, remain insufficient and divergent(16). Thus, they present important challenges for professionals involved in the prevention of occupational hearing loss(16).

As final considerations, we should highlight the limitation inherent to the study design as a cross-sectional type, since the differences found in cochlear function between groups cannot always be considered as sure signs of future hearing loss. For a real predictive value, we need longitudinal studies. Thus, in addition to encouraging the development of longitudinal studies, we suggest future studies highlighting the selection of more homogeneous groups through paired samples, considering audiometric and immittance tests for greater reliability in the selection of normal-hearing individuals, and developing studies of offshore workers that include exams capable of evaluating the peripheral as well as the central auditory system, such as the use of otoacoustic emissions with suppression, to better measure possible hearing changes in these workers, potentially exposed and little contemplated in the scientific literature.

CONCLUSION

Evoked otoacoustic emissions were more altered in the offshore group than in the onshore group of workers, with the highest proportion of failures occurring in the frequencies of 4 kHz for TEOE and 6 kHz for DPOAE. In this sense, the results suggest that exposure to noise and/or chemical substances can significantly contribute to changes in the cochlear function of seafarers, even before they present hearing complaints.

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MKSM: Conception and project; analysis and interpretation of data; writing of the article; finally, responsible for all aspects of the work in ensuring the accuracy and integrity of any part of the work. VMC: Relevant critical review of the intellectual content and final approval of the version to be published. TRG: Conception and design, analysis and interpretation of data. DCC: Conception and project; data collection and relevant critical review of intellectual content. LWM: Conception and project; data collection, analysis, and interpretation of data. MIKPA: Participation as an advisor, conception and project; analysis, relevant critical review of the intellectual content and final approval of the version to be published.