Auditory Threshold in Professional Divers Not Exposed to Noise

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Objectives: Otologic and audiometric evaluation of professional divers without noise exposure has been carried out to analyze the repercussions of this activity on their hearing.
Material and method: A total of 233 professional divers, working in a no noise environment, with an average experience of 9.6 years and 2074 lifetime dives, in a working depth between 10 m and 27 m, average 4.6 hours underwater were evaluated. This atypical population of divers did not follow any decompression schedule and engaged in diving in a purely empirical and intuitive fashion.
Results: Eighty-nine point two per cent presented symptoms of decompression sickness (DCS). Only 19.7% presented a mean hearing threshold below 20 dB while 73.5% had a mild hearing loss. Significant differences (*P*<.0001) were found in hearing thresholds at 3, 4, and 6 kHz when hearing thresholds were grouped by years of experience and diver's age. No such increase was found when the sample was grouped by DCS symptoms, vestibular symptoms, number of dives, or patent foramen ovale.
Conclusions: The presence of high-frequency sensorineural hearing loss in professional divers is related to their age and experience, even without a noisy working environment.

Key words: Diving. Adverse effects. Hearing loss. High frequency. Occupational illnesses.

Umbral auditivo en buzos profesionales no expuestos a ruido

Objetivos: Hemos realizado una revisión otoscópica y audiométrica de buceadores profesionales no expuestos a ruido, para evaluar la repercusión que esta actividad laboral tiene en la audición.
Material y método: Se analizó a 233 buceadores profesionales, con una experiencia promedio de 9,6 años y 2.074 inmersiones, que trabajan a profundidades de entre 10 y 27 m y una media diaria de 4,6 h de fondo. Se trata de una población atípica que bucea de forma intuitiva y empírica sin realizar paradas de descompresión regladas.
Resultados: El 89,2% presentó síntomas de enfermedad por descompresión. Sólo el 19,7% presentaba un umbral medio de audición por debajo de los 20 dB y el 73,5% presentaba una hipoacusia leve. Se encontró un significativo incremento del umbral auditivo en 3, 4 y 6 kHz al agrupar por años de experiencia y edad ($p < 0,0001$). No se observó este incremento al agrupar la muestra según tuvieran foramen oval permeable (FOP), síntomas de enfermedad por descompresión ni clínica vestibular o número de inmersiones.
Conclusiones: La hipoacusia neurosensorial en frecuencias agudas en buceadores profesionales está relacionada con la edad y los años de profesión, incluso en ausencia de un medio laboral ruidoso.

Palabras clave: Buceo. Efectos adversos. Hipoacusia. Alta frecuencia. Enfermedades profesionales.

INTRODUCTION

Ailments of the ear are the ones most often affecting divers and among their various manifestations, hearing loss stands out. Hearing loss has been associated with both professional and sports diving, but there is no consensus on its cause: exposure to noise, barotrauma, or decompression sickness (DCS) of the internal ear.[1-3] Most of the existing studies have been conducted on populations of divers, professional (civilian or military) or sport divers, who carry out their activity within the basic safety standards and after a medical examination.[4] These rules are taught in the training courses

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required to obtain the diving certification. The purpose of this study is to assess the hearing status presented by a particular population of professional divers who do not follow the basic safety standards, have not been subjected to a prior medical evaluation, have carried out a higher number of dives than usual and show a high rate of symptoms by DCS and other non-dysbaric accidents. Thus it is an exceptional population, perhaps unique in the world, which makes it possible to evaluate the harmful effects of diving practised outside the universally accepted safety limits.

We have analyzed their hearing thresholds according to multiple criteria (years of experience, age, presence of patent foramen ovale, number of dives, symptoms of DCS, vestibular symptoms). We compare their hearing with a control group of divers who do follow the safety rules.

The study of this population falls within a humanitarian aid programme developed by the Solidariedade Galega NGO aimed at improving the technical training (courses on diving accident prevention), and health training (installation of a decompression chamber and training of supervisor personnel) for divers in the Sechura Bay in the province of Piura (Peru), in order to reduce the high rate of work morbidity and mortality.

The importance of the programme is that the breeding and harvesting of the Peruvian scallop (*Argopecten purpuratus*), as well as other deep fishing activities, are the main economic activities of the Sechura Bay and support about 3000 jobs directly. The population of divers is estimated at around 1000 and indirectly supports a population of about 60 000 people spread over several populations with an administrative centre at Sechura.

METHOD

Study Group

We have analyzed a total of 244 professional divers, who came in voluntarily and unpaid, without any prior selection procedure. Most were attending courses on diving accident prevention taught by 2 of the authors, both qualified divers trained in underwater medicine (SFP and JHG). This activity was carried out between September 2 and 19, 2007, in collaboration with the Sechura Health Centre (Piura, Peru), where all the medical and radiological examinations were carried out.

The technique used by divers in Sechura Bay is a surrogate of umbilical diving or "narguille." Compressed air for breathing is injected via a hose using hand crafted compressors from a boat. No regulator is used, instead the hose is introduced directly into the mouth, controlling the air flow through the collapse of the tubing by pressure exerted through biting. No depth gauge or clock is used to control the depth, depth time or decompression pauses. No decompression tables or any other type of device is used to control the ascent. The work depths range between 6 and 40 m and the depth times between 2 and 6 h. The work carried out is the manual collection of different commercial species; therefore it does not involve exposure to noise or other potential causes of sonic injury.

Eleven subjects were discarded due to having been diving less than 1 year, 4 for having less than 100 total dives, 5 for employing apnoea diving technique, and 1 for presenting a left cophosis prior to the beginning of the diving activity. The sample finally comprised 223 individuals with a total of approximately 460 000 dives. For all of them, the assessment protocol applied included: *a)* history and general physical examination; *b)* survey of experience and diving technique; *c)* background compatible with DCS; *d)* non-dysbaric accidents; *e)* otolaryngology assessment (otologic and rhinosinusal symptom history, prior exposure to ototoxics or sonic trauma, microotoscopy, Toynbee test, impedanciometry, and threshold tonal audiometry); *f)* neurological evaluation; *g)* adiological evaluation (systematic simple x-ray of pelvis and other joints according to symptoms; and *h)* screening for patent foramen ovale using vascular Doppler with saline contrast. This last examination was conducted on only 219 divers, because 4 divers refused consent.

The audiometric and impedanciometric tests were all carried out by the same examiner, using a Siemens SD 25 audiometer and a Siemens Handtymp impedanciometer. The frequencies analyzed were 0.25, 0.5, 1, 2, 3, 4, and 6 kHz, following the technique of Carhart-Jerger.[5] The auditory threshold considered for a given frequency was the mean of both ears. A mean threshold (0.5+1+2+3 kHz/4) between 20 and 40 dB was considered as mild hearing loss, moderate between 40 and 60 dB, severe between 60 and 80 dB, and profound when the threshold was higher than 80 dB. The monaural and binaural hearing impairment was calculated following the rules of the American Academy of Otorhinolaryngology.[6]

Control Group

The control group consists of 19 sports divers (17 males and 2 females), with no prior exposure to ototoxics or sonic injuries. The mean age was 41 years (range, 17-61). The average diving experience is 4.5 years, and they have specific training and authorization for sports diving. All were subjected to the same questionnaire and medical examination as the study group, and the group of doctors was the same in both cases. They attended on a voluntary basis and without prior selection from a recreational diving club in A Coruña.

Statistics

The SPSS 14.0 for Windows programme was used. Student's *t* test was used for the comparison of means with a single variable and the Kruskal-Wallis test for the comparison of means with multiple variables.

RESULTS

All divers were male, with a mean age of 32.7 (range, 17-59) years. The mean diving experience was 9.6 (range, 1-32) years, 2074 average total dives (range, 100-7200), with a mean of 216 dives per year per diver. The average maximum depth was 25.2 m, the usual mean 13.5 m, and

a e 1. Incidence of Decompression ic ness (D) ymptoms (n 223)[a]

Events by D	*o. (%)*
one	24 (10.8)
Isolated	98 (43.9)
Repeated	37 (16.1)
Multiple	64 (28.7)

[a]Isolated indicates 1-2 events; repeated, 3-4 events; multiple, more than 4 events.

a e 2. Incidence of ymptoms related to Decompression ic ness (D)

igns ymptoms	*o. (%)*
Joint pain	183 (82)
in	132 (59.1)
Vestibular	51 (23.3)
Dyspnoea	44 (19.7)
Medullar	35 (15.6)
erebral	30 (13.4)

a e 3. Incidence of Problems Related to Middle Ear or Paranasal inuses ompensation and Otic equelae of Immersion

Variable	*ever, o. (%)*	*Occasionally, o. (%)*	*onstantly, o. (%)*
Difficulty in compensating ear	70 (31)	110 (50)	43 (19)
Difficulty in compensating sinuses	55 (25)	140 (63)	28 (12)
Otic sequelae of immersion	139 (62)	67 (30)	17 (8)

the mean depth time 4.6 h. In addition, 3.5% (7/223) were smokers. Only 1 of the divers (0.4%) reported following decompression tables routinely. In all other cases decompression is irregular and intuitive, based, when deemed appropriate, on the following scheme: slow climb up to half the depth of work, first stop of 10-15 min, new ascent to half the remaining depth, second stop of 20-30 min and eventually one last stop at half the remaining depth (around 3 m) of about 45-60 min.

Decompression Sickness

As a result of the erratic decompression pattern described, 89.2% (199/223) reported having experienced symptoms of DCS of varying intensity and frequency (Tables 1 and 2).

Otorhinolaryngological Evaluation

The incidence of problems in ears and sinuses during immersion, as well as later problems (earache, deafness, otorrhagia, ear suppuration, rhinorrhagia), is shown in Table 3.

Otoscopy

The microotoscopic examination showed complete eardrums with normal colour and appearance in 96.5% of the right ears and 97.4% of the left ears. Four (1.8%) right and 5 (2.2%) left barotraumatisms were found, all of grade II; 2 (0.5%) right and 3 (1.3%) left perforations were also found. One patient presented left chronic otitis media.

Tympanometry

In the right ear, 91% of patients had normal tympanometry, as did 86% in the left ear. They presented curves of type B in 4.4% of the right ears and 9.7% of the left.

The Toynbee test was positive in 77.1% of the right ears and 70.9% of the left.

Audiometric Evaluation

Sixty per cent of patients (135/223) reported worse hearing than before starting to dive. We found no transmission hearing loss. In the audiometric evaluation, 19.7% (44/223) presented normal hearing, 73.5% (164/223) mild hearing loss, 6.7% (15/223) moderate hearing loss. The mean hearing threshold was 33, 36, 24, 22, 28, 31, and 33 dB for 0.25, 0.5, 1, 2, 3, 4, and 6 kHz, respectively. The percentage of divers with a binaural hearing over 10% was 10.7% (24/223). We found no significant differences when relating the mean hearing threshold with that of the control group (Figure 1), nor when they were compared by groups according to the number of dives (Figure 2), having suffered vestibular symptoms, having shown symptoms of DCS, or presenting a patent foramen ovale. Highly significant differences (P<.0001) were found between the thresholds at frequencies of 3, 4, and 6 kHz depending on the age and number of years worked (Figures 3 and 4).

DISCUSSION

Both professional and sports diving, have been associated with an increased prevalence of hearing loss.[13,7] Whether this loss is associated with dysbaric accidents affecting the inner ear (DCS, barotraumatisms), the result of exposure to noise or with diving as a risk factor even when uneventful, is an issue that is not clear.[1-3] It is virtually impossible, and it would be ethically reprehensible, to design a prospective study to analyze the impact of diving not subject to hearing safety parameters. The population analyzed in this study carry out their work in totally intuitive conditions, disregarding the safety standards recommended by international agencies and without prior formal training. As a result of this, immersion times, working depth, and speed of ascent are the cause of high morbidity and mortality. In 2006 there were no fewer than 20 deaths, which would correspond to a rate of 2000 deaths per 100 000 divers/year. This figure may be even greater when one considers that there is no record of work accidents or formal register of deaths and that the social and work circumstances

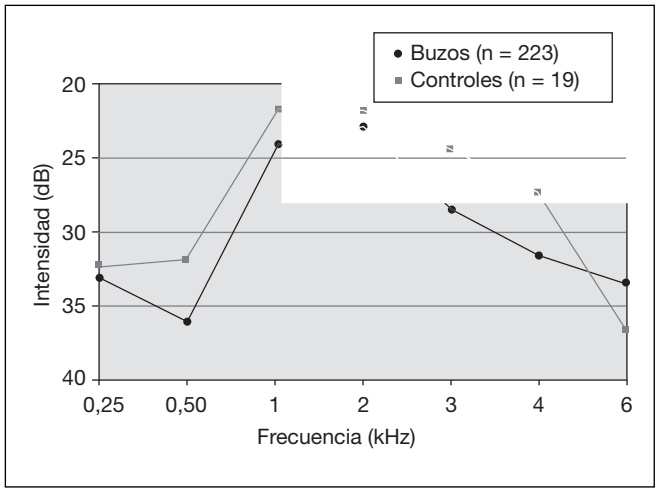

Figure 1. omparison of mean thresholds between divers and controls.

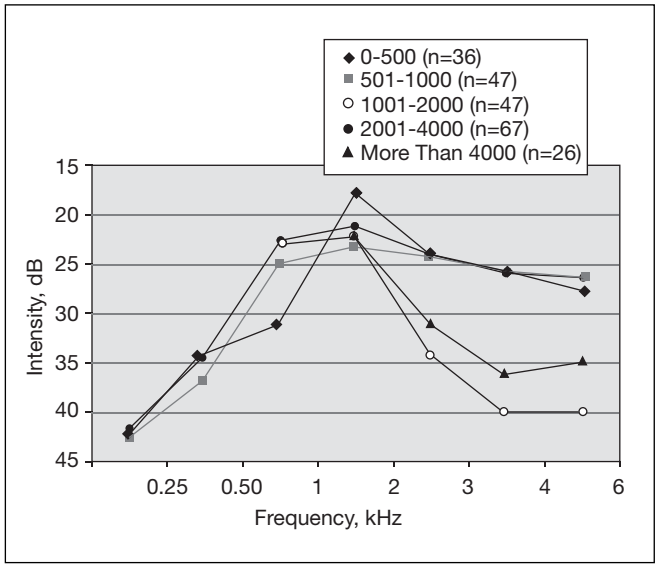

Figure 2. omparison of thresholds by number of dives.

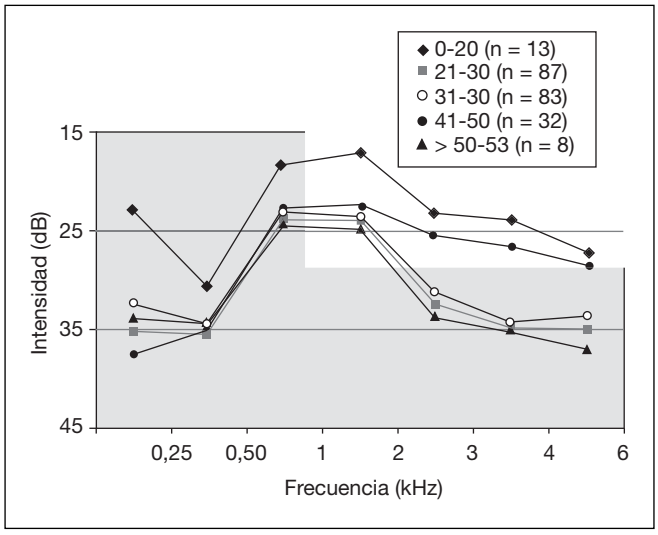

Figure 3. Hearing thresholds by age groups. or 3, 4, and 6 Hz, *P* .0001.

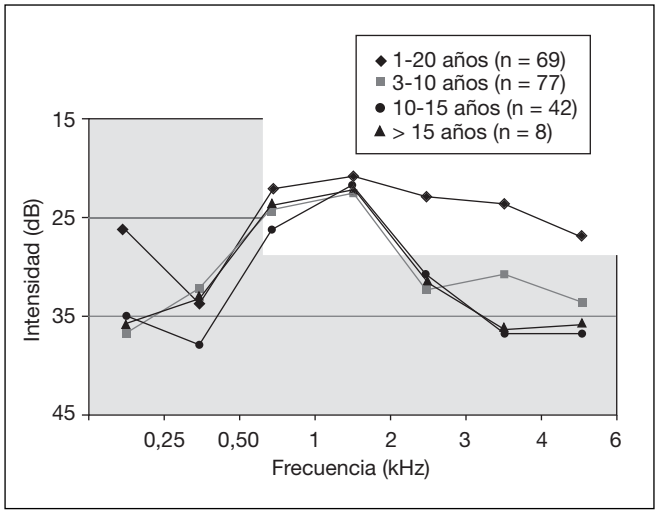

Figure 4. Hearing threshold by years of diving. or 3, 4, and 6 Hz, *P* .0001.

surrounding the activity hinder access to transparent data.[8,9] By way of reference, the death rate reported by the Occupational Safety and Health Administration in the United States, for professional divers in Alaska between 1990 and 1997 was 180 deaths per 100 000 divers/year; these divers have an increased work risk due to carrying out their activity in the construction and maintenance of oil pipes.[10] A comparison of the indices (2000 vs 180) gives an idea of the magnitude of the problem in Sechura.

Around 89% of the divers report symptoms of DCS, which represents an approximate incidence of 181 DCS events per 10 000 dives. The treatment of DCS symptoms is also empirical and involves milk, dextropropoxyphene, and in those cases considered most serious through recompression in water. The latter procedure is common in groups with similar diving technique and identical shortcomings.

The most significant finding of the audiometric study was sensorineural hearing loss at high frequencies.

This impairment, described in other series, was associated with age, years of work, exposure to noise, and use of tobacco[3,12,13]; significant differences were only found in the association of diving with smoking.[13] The contribution of our study is the finding of a significant deterioration in the threshold at high frequencies (3, 4, and 6 kHz) depending on the years of work and the age of patients in a large sample of divers not exposed to noise during their work and non-smokers in 96.5% of cases, which shows that professional diving, by itself, may increase the hearing threshold at high frequencies regardless of noise. Sonic trauma has been the most frequently cited element to justify hearing loss at high frequencies in divers, and this is due to the fact that most professional divers work in environments with intense noise.

This justifies the sensorineural hearing loss at high frequencies in a series comparing 26 divers with 26 workshop operatives, with similar smoking habits and exposure to noise level, in which no differences were found.[14] A study in Great Britain with a large sample, 285 professional divers with a minimum of 5 years' experience, found no differences in the auditory threshold when compared with non-diver controls; the authors postulate that the professional diver does not lose more hearing than the normal population.[15] Our results provide data which clearly indicate hearing loss at high frequencies, and that this loss is significantly related to the years of work and the patient's age.

The work of Edmonds[16] is an interesting reference that evaluates hearing in a population of the *Haliotis roei* mollusc gatherers, on the west coast of Australia. Unlike our population, divers studied by this author follow established safety guidelines and also present neurosensorial hearing loss at high frequencies, with hearing thresholds above those of the normal population and those in a control sample with similar ages.

Although barotraumatism is the most frequent cause of diving ailments, only 4% presented obvious signs of barotraumatism, all of type II. Being experienced divers makes the most common middle ear compensation problems less frequent, and only problematic in the course of infection of the upper airway. It is in these cases that there are reports of the onset of pain in the frontal area at the start of immersion or rhinorrhagia in the following hours.

Divers with a perforated eardrum continued diving without experiencing alternobaric or temperature difference vertigo. The reason may be the type of wetsuit they employ, popularly known as "pig skin." They are composed of a spongy neoprene up to 22 mm thick, which maintains the external hearing conduit nearly sealed, without producing the annoying compression effect of tighter neoprenes. After diving with their equipment, for 40 minutes at 8 m depth, we could verify that the divers are virtually dry when they take off their suits.

Despite the high incidence of symptoms of decompression sickness (Table 1) and their severity (Table 2), patients do not present any special impact on their hearing. Vestibular symptoms, such as dizziness, tinnitus, or deafness, have not been associated with an increased incidence of high-frequency sensorineural hearing loss. Other series have described up to 75% of cochleovestibular sequelae in divers suffering from decompression sickness or inner ear barotraumatism.[17,18] Recompression in water is a thing of the past, but is still applied in other contexts with similar deficiencies, where a hyperbaric chamber is not available within a reasonable distance. In any case, it is reserved for missed decompression or minor symptoms, with the diver being monitored constantly and following the therapeutic tables.[4]

The total absence of exostosis is striking. This hyperostotic injury has been linked with irritation caused by contact with cold water, becoming more frequent the longer the exposure,[19,20] and there is anthropological evidence of up to 30% exostosis of the external auditory canal in this region of the Pacific.[21]

Patency of the foramen ovale, present in 10% of the sample and associated with an increased risk of DCS in divers,[22] was not observed in our series to be associated with a significant increase in the number of DCS events or cochlear sequelae.

The hearing threshold at high frequencies (3, 4, and 6 kHz) is significantly increased in professional divers with an increased number of dives and years of work, and this deterioration of the threshold occurs despite not being exposed to noises causing sonic trauma. Symptoms of decompression sickness, number of dives, patient age, patent foramen ovale, or vestibular clinic do not significantly alter the threshold at the same frequencies.

Despite the minimal safety precautions adopted by the population of divers at Sechura Bay, the impact on their hearing is minimal compared with the high bone and neurological morbidity caused by DCS. Morbimortality related to this work is increased by a factor of 100 with respect to any reference available and can only be reduced through training and the provision of technical resources for the diving population, incorporating the basic elements to carry out an activity which, following elementary safety guidelines, should not lead to workplace accidents of the magnitude and frequency present in Sechura Bay.

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