INTRODUCTION

Little is known about long-term health effects in divers who use air as breathing gas and dive to shallow sea levels. As for the possible auditory effects of diving, decompression sickness (DCS) and barotraumas may contribute to loss of hearing (1). DCS may appear after the formation and growth of inert gas bubbles within micro vessels and in the otic fluid. This takes place whenever pressure drops rapidly during the ascent from a dive to a lower level than required to keep gas soluble (2). Inner ear barotrauma is connected with difficulties in equalising pressure in the middle ear. It occurs mostly during the descent phase of a dive, when raised ambient pressure leads to a relative underpressure in the tympanic cavity (1). Head injury and infection of the ear is also known to cause loss of hearing among divers (1). In addition, there may be a high noise level in the working environment of the diver (3). Studies of professional divers performing saturation diving, construction diving, inspection and/or navy diving have shown a high prevalence of hearing impairment (4,5) even among divers with no history of noise in the workplace (6). Two studies of construction divers suggest a faster deterioration in hearing at high frequencies, most pronounced in the left ear (7,8). Other studies indicate, however, that auditory function in divers is not different from that of the general population, in spite of noise exposure, diving experience and barotraumas (9).

The present cohort has been subjected to follow-up at three, six (7,10) and now twelve years. The aim of this twelve-year, prospective follow-up study was to examine possible hearing deterioration in a group of young occupational divers and to see if changes in hearing thresholds were related to diving exposure.
MATERIAL AND METHODS

The cohort

The divers, all men, attended a 15-week diving course at a commercial school for divers. The baseline registration of the entire group of divers lasted a two year period from autumn 1992 to autumn 1994. Sixty students from seven successive courses were asked to participate in the study of auditory function. A study of neuropsychological function was initiated later and did not include students from the first and the two last courses and thus included 50 of the original cohort. We decided to do a twelve-year follow-up of this subcohort. Among the original 50 divers, two had died (one in a diving accident), one had moved abroad and one was impossible to find, leaving 46 for further study. All of these divers were able to be contacted and 30 of them agreed to participate in the study, giving a participation rate of 65%.

One diver had experienced decompression sickness (DCS) or barotrauma of his right ear, which had lead to a reduction in hearing at high frequencies; this ear was thus excluded from the analysis.

The mean age of the 30 male divers at the start of the follow-up was 25 years (SD=4.5, range: 18-32 years). Eleven (37%) were daily smokers, at start, and nine (30%) at the 12-year follow-up. In the analysis smokers were defined as subjects who were smokers at baseline registration.

To illustrate differences within the cohort we compared low exposure divers with high exposure divers (table I). The low exposure group consisted of 17 men with cumulative diving exposure less than 600 dives and the high exposure group consisted of the remaining 13 men. The low exposure divers were not engaged in commercial diving at the 12-year follow-up. They were a little younger compared to the 13 high exposure divers who performed occupational diving part or full time. The low exposure divers had a significantly higher cumulative cigarette exposure compared to the high exposure divers.

Assessment of exposure.

Information on both occupational and recreational diving activity during the follow-up period was recorded by questionnaire. For some of the divers, information on diving activity was also available from logbooks. The diving activity declined during the follow-up period. The divers had performed a median number of 477 dives (range: 40-4458) during the cumulative follow-up period. Dives to depths of 10 meters or less made up more than 60% of the dives performed by the total cohort.

Most of the diving was performed using air as breathing gas. This included a surface-supported or self-contained underwater breathing apparatus that allows the diver to carry his air supply with him (SCUBA equipment). Usually the divers wore umbilical-type air

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<th>Table 1. Characteristics of the 30 divers during the 12-year follow-up</th>
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supplied demand equipment, a Kirby Morgan band mask 18B or a Kirby Morgan superlite helmet 17B and neoprene suits while diving.

**Diving-related accidents**
As for diving-related accidents, no accidents were reported by the divers from the time before they started diving school. During the first follow-up period of three years, three episodes of decompression sickness (DCS) or barotrauma occurred. During the last nine years five such episodes were reported, giving a total amount of eight episodes during the 12-year follow-up.

**Divers’ noise history**
The divers’ history of possible hearing loss not related to diving exposure (e.g. from shooting/hunting or sudden explosion) and occupational noise exposure was recorded by questionnaire.

**Auditory examination**
The auditory examination was performed three days or more after a dive, using the Diagnostic Audiometer model TA 155. For the first three years of follow-up the audiometer was calibrated annually in accordance with ISO 389. At the six-year and twelve-year follow-up examination a Micromate 304, Screening Audiometer (Madsen Electronics, Denmark), ISO 9002 certificated was used. The auditory function was measured while the divers sat inside a T-cabin model 70, type 3240, which is a sound-treated booth manufactured by C-A Tegnér, Sweden. The same technician, a physician, performed all tests after initial otoscopy, but pneumatic otoscopy was not performed. The frequencies tested for air conduction thresholds were 0.25, 0.5, 1, 2, 3, 4, 6, and 8 kHz. The examinations were performed in accordance with the Norwegian Directorate of Labour Inspection’s recommendations (11).

This study was approved by the Regional Ethical Committee for Medical Research in Oslo, Norway and all divers gave their written informed consent at the start of the study and at the final follow-up. Anonymity of the subjects was secured throughout the study period.

**Statistics**
Student’s paired t-test, two sided, was used in the data analysis to examine differences between the divers’ performance at the start of the diving career and twelve years later. The same test was used to study possible differences between the left and the right ears of the divers. A significance level of 5 % was chosen (12). All data are expressed as means (SD) or median (range). The statistical language R was used for the data analysis (www.r-project.org).

The association between diving and hearing threshold levels at the different frequencies was analysed by a linear mixed model for repeated measures using the nlme package in R (13). A mixed model takes into account the dependency of repeated observations by adding random effects. Here, random effects were added for subject (diver) and for side of ear combined with frequency, where the latter random effect was nested within subjects. As fixed effects, in addition to cumulative number of dives, the model included age, frequency and follow-up year. We also checked for occupational noise exposure and shooting/hunting/sudden explosion exposure but these covariates were not significant and were excluded from the final analysis. As hearing was not significantly different between left and right ear, we combined observations for the two ears.

We also explored the possible non-linear relationship between diving and hearing function, and also between age and hearing, using an additive mixed model for repeated measures (mgcv package in R) (14). A linear additive mixed model is a generalisation of a linear mixed models by the use of smooth
function terms instead of linear terms for continuous covariates. Here, smooth function terms were used for number of dives and for age.

RESULTS

After the 12-year follow-up period, reduced hearing ability was observed at 0.25, 0.5, 2, 3 and 6 kHz in the right ear and 3, 4 and 6 kHz in the left ear relative to the baseline values for the total group of divers (table 2). A comparison of the change in hearing threshold levels for the left ear compared with the right ear showed no significant difference.

We first explored a possible non-linear association between hearing threshold levels and \(\log(\text{number of dives})\) using an additive model. Age is the most important explanatory variable for loss of hearing, and it is particular important to separate between the effects of diving and age. Figure 1 shows the effect of age and diving on hearing at frequencies 4 kHz, 6 kHz and 8 kHz both ears combined. At 6 kHz there is a strong age effect but no significant diving effect. For 4 and 8 kHz there seem to be a significant deterioration of hearing for \(\log(\text{number of dives})\) larger than 6.5 approximately (i.e. for number of dives \(>650\) approximately). The estimated trends at the different frequencies were flat or close to an exponential term, hence we used number of dives untransformed in the analysis. The analysis using a linear mixed model for both ears combined are shown in table 3.

DISCUSSION

In the present study we have observed a reduction in hearing function affecting the right ear of divers.
and left ear during a 12-year follow-up period of young divers. The results indicate that diving activity affects both ears combined at 4 and 8 kHz.

A deterioration at low frequencies on the right ear was found among the divers in our study but no significant association with diving exposure was revealed. Reduction of hearing function at low frequencies has been reported among divers working in conditions absent of noise (15,16). A cross-sectional study of sport divers did not, however, detect any difference in the hearing thresholds between sport divers and non-divers (17). Haraguchi et al. (15) and Molvær et al. (4) found that the hearing of divers over a period of 5 or 6 years deteriorated faster than in the reference populations, and that the deterioration was most pronounced at the frequencies of 0.5 kHz, 1 kHz (15) and 2 kHz (4,15). The deterioration at low frequencies in our study is interesting, since repeatability in test-retest of auditory function is especially good at 1 and 2 kHz and that hearing loss at 2 kHz is less pronounced than at 4 kHz during the first years of noise exposure (18,19).

In our study, reduction in hearing acuity was found at frequencies of 3, 4 and 6 kHz during follow-up. Similar findings have been described by others (5, 20). We found an association between the reduction in auditory function in both ears at 4 and 8 kHz and cumulative number of dives during the 12-year follow-up. High frequency sensorineural hearing loss has also been found in a cross-sectional study of naval divers who were compared with other soldiers with equivalent exposure to noise from gunshots and among recreational divers (21, 22).

The findings of hearing deterioration among a fixed cohort of divers in a follow-up design is methodologically the best way to detect effects. Two recent studies (23, 24) did not reveal any reduction of hearing function due to diving. Other longitudinal studies of divers’ hearing function have, however, shown the same longitudinal deterioration among divers as found by us (4, 15).

Although controlling for both occupational noise and leisure gun shooting, noise exposure as a contribution to our results cannot be ruled out. Reduced hearing function at 4 and 6 kHz has been related to noise exposure in other studies (25). Noise affects younger subjects especially at 4 kHz, causing rapid deterioration of hearing during the first 10-15 years of exposure. Hearing loss at 6 and 8 kHz seems to be closely associated with noise exposure as well (25, 26). Divers may be exposed to both air- and waterborne noise during work. In the working environment of divers, explosions and helmet noise in addition to noise in decompression chambers or due to hydraulic tools may generate noise up to 90-105 dB (27, 28).

Research suggests that the human
hearing range is reduced from 130 dB in air to 55-60 dB in water (29). Since sound does not disappear under water as fast as in air, this reduction may cause the diver to be less resistant to noise (29). Exposure to a combination of vibration and noise causes higher temporary threshold shifts (30). When professional divers use vibrating tools this might potentiate the possibility of noise-induced hearing loss.

Barotrauma, DCS and noise are regarded as the main causes of hearing loss among different diving groups. Other ototoxic factors, both of physical and chemical nature, associated with recreation (i.e. cigarette smoking (31) and occupation could affect hearing acuity. Occupational exposures, organic solvents, gases like carbon monoxide and heavy metals such as lead, arsenic and mercury could promote hearing impairment in both low and high frequencies (32) also among divers. As for high pressure exposure, animal studies show degeneration of the organ of Corti (33) in addition to perilymphatic haemorrhage (34) as a result of direct effect of repeated compression and decompression (34). A study of Meller et al. (35) however, could not confirm alteration in the animals hearing after exposure to repeated high pressures.

During the study 35% of the cohort was lost to follow-up. There were no obvious differences comparing the drop outs with those who participated at the final follow-up. The longitudinal design with a follow-up starting as the divers start their training combined with repeated measurements during the 12 year follow-up is a strength in this study. We thus have reasons to believe that the results are valid.

In conclusion, the hearing function of the divers over a 12-year follow-up period shows a slight reduction at both low and high frequencies on both ears. The reduced hearing ability on both ears at 4 and 8 kHz is related to diving exposure.

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REFERENCES


