Hearing Threshold in Sport Divers

Is Diving Really a Hazard for Inner Ear Function?

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Objective: To investigate the effect of scuba diving on the hearing threshold of sport divers who have no history of excessive noise exposure or of diving-related inner ear damage.

Design: Cross-sectional controlled comparison study.

Setting: General sports diving community.

Participants: Sixty sport divers with an average of 650 dives each and at least 4 years of diving experience (mean, 10 years) were compared with a control group of 63 non-divers from our hospital staff or patients referred for rhinologic problems or benign tumors of the salivary gland.

Main Outcome Measure: After microscopic otoscopy and tympanometry, we used pure-tone audiometry to measure the hearing threshold for air and bone conduction. The participants were divided into 3 age groups, and the hearing test results for both ears combined were statistically compared.

Results: There were no statistically significant differences in the hearing thresholds between sport divers and nondivers.

Conclusions: The reduced hearing levels of professional divers found in other studies are probably due to the high noise levels that they have to deal with or may be a result of inner ear accidents.

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DIVING PUTS THE INNER EAR at risk. Inner ear barotrauma (IEB)1-7 and inner ear decompression sickness2-4,8-16 can lead to permanent sensorineural hearing loss, tinnitus, and vertigo. If hearing function is measured only by air conduction, there is the possibility that the residual damage of middle ear barotrauma, which is the most common accident in diving,17 may influence the hearing test results.

Whether uneventful scuba diving in the absence of a decompression incident is a risk factor for cochlear disorders is a matter of debate.18-24 Most studies of diving-associated hearing loss reveal an association with occupational noise exposure.18,21-24 Therefore, the effect of acoustic trauma or potential harmful effects of increased pressure and partial pressures of breathing gases cannot be differentiated.

The purpose of this study was to examine the cochlear function of nonprofessional divers with considerable diving experience but no increased exposure to noise during work and leisure time. These divers did not have a history of inner ear decompression sickness or IEB. The results were compared with those of a group of nondiving control subjects.

METHODS

DIVERS

Ninety-one sport divers who had participated in a previous study at the University Hospital of Heidelberg, Heidelberg, Germany,25 were asked to return a questionnaire detailing their medical and diving history. Sixty-four divers returned their questionnaire and underwent audiometric testing. One diver was excluded because brainstem audiometry and magnetic resonance imaging revealed an acoustic neuroma. Three divers who reported IEB with residual hearing loss and tinnitus were also excluded. We identified 60 divers (43 men and 17 women) ranging in age from 22 to 60 years (mean, 37 years; SD, ±9 years) and subdivided them into the following 3 age groups: 18 to 30 years (group 1; n=21), 31 to 40 years (group 2; n=21), and 41 to 60 years (group 3; n=18). The average diving experience was 10 years (range, 4-27 years), and the mean number of dives completed was 650 (range, 195-3500). All dives were performed using air as the breathing gas. Exposure to noise during military training, at work, or during leisure time was recorded by means of questionnaire. None of the subjects had been...
exposed to noise levels of more than 85 dB as defined by the German authorities on working place safety. Other potential harmful effects on inner ear function such as previous head injury, use of ototoxic antibiotics, exposure to neurotoxic or ototoxic substances, and history of otologic diseases were also recorded and classified with positive or negative results.

Clinical assessment included microscopic otoscopy, tympanometry, and acoustic stapedius reflex measurements. Pure-tone thresholds were measured with an Audiometer CA 540/1 (Hortmann Neuro-Otometrie, a division of GN Otometrics GmbH & Co KG, Neckartenzlingen, Germany) according to the German standards (International Organization for Standardization 8253). The same examiner (C.K.) using the same audiometer performed all auditory tests. Individual air conduction hearing thresholds for a given frequency were defined as the mean of both ears.

CONTROL GROUP

The control group consisted of 63 patients of our outpatient clinic and staff who had a negative otologic history and were free of ear-related symptoms at the time of evaluation (30 men and 33 women). The age range in the control group was 18 to 59 years (mean, 32 years; SD, ±9 years). The control group was divided into the same 3 age groups as the subject group of divers, including 33 in group 1, 17 in group 2, and 13 in group 3. The control subjects answered the same questionnaire, with the exception of questions related to diving. Otologic assessment included microscopic otoscopy, tympanometry, and pure-tone audiometry, including air and bone conduction. The audiometric testing was performed with the same equipment by the same examiner who examined the divers. None of the controls had acute or chronic middle ear disease or middle ear ventilation difficulties as measured by means of tympanometry.

The local ethics committee approved the study, and all participants gave their written informed consent.

STATISTICS

Statistical analysis was performed with WinStat for Excel software (Version 2000; R. Fitch Software, Staufen, Germany). The significance level was defined as P<.05. The results of the pure-tone audiometry of the 3 age groups were compared for both ears combined. A Mann-Whitney test was used for the comparison of the hearing thresholds. Because of multiple testing, an adapted Bonferroni correction was applied. The Fisher exact test was used where dichotic variables were analyzed. NQuery Advisor software (Statistical Solutions, Saugus, Mass) was used to calculate the power of the statistical testing.

RESULTS

MICROSCOPIC OTOSCOPY

Microscopic otoscopy did not indicate acute inflammation of the tympanic membrane or the outer ear canal in any of the divers or controls. In 6 divers (10%), atrophic or hypertrophic scars of the tympanic membrane were seen.

TYMPANOMETRY AND MEASUREMENT OF STAPEDIUS REFLEXES

The divers and controls underwent tympanometry to measure physiological tympanic pressures. Ipsilateral and contralateral stapedius reflexes were present in both ears in all divers.

PURE-TONE AUDIOMETRY

The following frequencies were tested by means of air conduction: 0.5, 1, 2, 4, 6, 8, and 10 kHz. Bone conduction was measured at 0.5, 1, 2, 4, and 6 kHz. Conductive hearing loss was not found in the group of divers or in the controls. Individual air conduction hearing thresholds for a given frequency were defined as the mean of both ears.

MEDICAL HISTORY OF DIVERS AND CONTROLS

Testing with the Fisher exact test showed no significant differences in the medical history of the 2 groups. In particular, history of noise in the leisure time and at work did not differ between groups.

HEARING TEST RESULTS

Mann-Whitney Test With Bonferroni Correction

We compared the hearing test results of divers and controls in 7 frequencies in 3 age groups with a Mann-Whitney test. Because of the multiple testing, we had to use an adapted Bonferroni correction. In our study, we performed 21 Mann-Whitney tests with a significance level of 5%, and therefore we expected at least 1 statistically significant difference where one does not exist. Use of an adapted Bonferroni correction resolved this problem.

Comparing the hearing test results of the divers and controls with the Mann-Whitney test showed no significant differences between all age groups in all tested frequencies.

Power of Statistical Comparison

To find a difference of the hearing threshold between 2 different groups is difficult because of the high variance of the hearing levels in healthy persons. This leads to high SDs.

We defined a difference between divers and controls of 10 dB or more to be of clinical relevance. For this artificial difference of 10 dB, we wanted to know how big a group had to be to gain a power of 90% at a significance level of 5%. We calculated the group size with NQuery Advisor software, with the following results: (1) with an SD of 2, a group size of 3 persons would be necessary to reach a power of 90%; (2) with an SD of 10, a group size of 23 persons would be necessary to reach a power of 90%; and (3) with an SD of 15, a group size of 86 persons would be necessary to reach a power of 90%.

Therefore, we can say that in the frequencies where the SD ranges from 2 to 10, the group size of this study was appropriate. At the frequencies where the SD is 15 and higher, the group size of this study was too small to reach a high statistical power.

Group 1

Hearing thresholds were not significantly different between divers and controls aged 18 to 30 years. Results are shown in Table 1 and Figure 1.
At the frequencies of 0.5, 1, 2, 4, 8, and 10 kHz, the group size was appropriate to find a significant difference. At 6 kHz with an SD of almost 15, the group size needed to find a potential difference of 10 dB with a significance level of 5% would have to be 86. Therefore at 6 kHz, the group size reduces the calculated power to 64%.

### Group 2

There were no statistically significant differences between divers and controls aged 31 to 40 years. The results are shown in **Figure 2** and **Table 2**.

The group size was appropriate at the frequencies 0.5, 1, 2, 4, and 6 kHz. At 8 and 10 kHz, the SD was 15 or more, and the statistical power in these frequencies was reduced to 50%.

### Group 3

There were no statistically significant differences between divers and controls aged 41 to 60 years. The results are shown in **Figure 3** and **Table 3**.

This was the smallest group with the highest SD. The group size was appropriate in the frequencies 0.5, 1, and 2 kHz. At 4 and 8 kHz, the power was about 75%, and at 6 and 10 kHz, the power was reduced to 40%.

### COMMENT

The following well-recognized factors can affect the inner ear in divers: acute IEB, inner ear decompression sickness, noise, and potentially chronic effects of the breathing gases.

A number of studies have compared the hearing threshold in professional divers. In 1961 in a group of 62 Royal Navy divers and submarine escape training in-

**Table 1. Average Hearing Loss of Both Ears Combined in the Groups Aged 18 to 30 Years**

<table>
<thead>
<tr>
<th>Frequency, kHz</th>
<th>Divers (n = 21)</th>
<th>Controls (n = 33)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>4.48 (3.42)</td>
<td>6.64 (4.23)</td>
</tr>
<tr>
<td>1</td>
<td>2.08 (2.23)</td>
<td>3.09 (2.86)</td>
</tr>
<tr>
<td>2</td>
<td>4.72 (6.45)</td>
<td>3.88 (4.02)</td>
</tr>
<tr>
<td>4</td>
<td>9.55 (11.52)</td>
<td>7.09 (5.67)</td>
</tr>
<tr>
<td>6</td>
<td>14.98 (14.87)</td>
<td>11.62 (7.27)</td>
</tr>
<tr>
<td>8</td>
<td>12.23 (10.31)</td>
<td>10.24 (6.95)</td>
</tr>
<tr>
<td>10</td>
<td>10.78 (11.72)</td>
<td>6.77 (7.58)</td>
</tr>
</tbody>
</table>

*There were no significant differences between groups by Mann-Whitney test after Bonferroni correction. Especially at 10 kHz, there were high SDs, and therefore the statistical comparison lost power in this frequency.

**Table 2. Average Hearing Loss of Both Ears Combined in the Groups Aged 31 to 40 Years**

<table>
<thead>
<tr>
<th>Frequency, kHz</th>
<th>Divers (n = 21)</th>
<th>Controls (n = 17)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>5.60 (4.84)</td>
<td>6.62 (5.02)</td>
</tr>
<tr>
<td>1</td>
<td>3.40 (3.24)</td>
<td>4.35 (4.01)</td>
</tr>
<tr>
<td>2</td>
<td>6.12 (4.71)</td>
<td>4.74 (5.33)</td>
</tr>
<tr>
<td>4</td>
<td>12.07 (11.26)</td>
<td>10.32 (7.29)</td>
</tr>
<tr>
<td>6</td>
<td>17.90 (12.02)</td>
<td>16.44 (7.11)</td>
</tr>
<tr>
<td>8</td>
<td>16.00 (14.68)</td>
<td>14.18 (8.76)</td>
</tr>
<tr>
<td>10</td>
<td>20.02 (17.78)</td>
<td>14.12 (13.11)</td>
</tr>
</tbody>
</table>

*There were no significant differences between groups by Mann-Whitney test after Bonferroni correction. At 8 and 10 kHz, there were high SDs, and therefore the statistical comparison lost power in these frequencies.

**Figure 1.** Hearing thresholds for divers and nondivers in the groups aged 18 to 30 years. Average hearing loss in both ears was combined. There were no significant differences between groups.

**Figure 2.** Hearing thresholds for divers and nondivers in the groups aged 31 to 40 years. Average hearing loss in both ears was combined. The divers showed marginally poorer hearing levels, but the differences were not significant.

**Figure 3.** Hearing thresholds for divers and nondivers in the groups aged 41 to 60 years. Average hearing loss in both ears was combined. There were no significant differences between groups.
structors, a high-frequency hearing loss was found in most of the divers.27 However, these divers had been exposed to gunfire and machinery noise during their naval careers, and noise could not be excluded as the causative mechanism.27

An intriguing finding was a prevalence of 60% of hearing impairment in a group of abalone divers who had not been exposed to noise.19 These divers, however, had been subjected to an extraordinary compression-decompression stress by a mean history of 6 years of diving with an average diving depth of 15 to 20 m during 4 hours on 100 days per year. The divers with recognizable hearing loss in that study remembered having barotrauma in the past. Therefore, residual damage after diving accidents may mask putative chronic effects of breathing air under hyperbaric conditions. In addition, hearing thresholds found in divers were compared with thresholds of controls from a different study.

One hundred sixty-four professional Norwegian divers22 subdivided into different age groups and hearing thresholds were compared with a standard population from Norway.22,28 Young divers were found to have better hearing compared with the reference group, and with increasing age this difference decreased. The authors claimed that hearing deteriorates faster in professional divers with increasing age. These results were confirmed when 116 divers were reexamined 5 years later. Noise at work and barotrauma were thought to contribute to the rapid deterioration of hearing in the professional divers.21

It is postulated that the human hearing range is reduced from 130 dB in air to 55 to 60 dB in water. The reduction causes the diver to be less resistant to noise underwater because acoustic energy underwater does not resolve as fast as in air.29 In addition, sawing, drilling, and grinding underwater may give rise to noise levels of 90 to 105 dB,30 and noise from the air stream venting inside underwater helmets can reach average noise levels of 93 to 99.5 dB.31 Most of the studies examined professional divers who had been exposed to gunfire or other noise at work.21,22,27 Noise was likely the main cause of the altered pure-tone thresholds.

This interpretation is supported by the fact that pure-tone thresholds of divers who had been exposed to noise underwater are similar to those obtained from control subjects who had been exposed to noise on land. In a cross-sectional study, auditory function was compared in 26 Norwegian construction divers and 26 workshop workers. Both groups had been exposed to noise, and divers had less hearing impairment at low frequencies (0.25 and 0.5 kHz).24

Another study from Skogstad et al23 examined 54 occupational divers at the beginning of their diving career and 3 years later. That study subdivided the divers into groups of low exposure (<100 dives in 3 years) and high exposure (≥100 dives in 3 years). Skogstad and coworkers did not find a statistically significant difference for both ears combined between both groups. Compared with the external control group from Molvaer et al,28 the divers even had better hearing levels. One should expect that divers with high exposure to diving should have poorer hearing levels because they have more contact with breathing gases under increased ambient pressure and work longer underwater and therefore spend more time in a noisy environment. However, the low-exposure group might have worked in a noisy environment, too, when they were not underwater.

These findings are confirmed by the data of Benton,24 who examined 281 commercial divers. He investigated the audiometric records of a group of United Kingdom professional divers, all of whom had been examined by an approved medical examiner. All divers underwent a hearing test between 1989 and 1992 and had a minimum of 5 years of diving experience. The divers were divided into 7 age groups ranging from 25 to 60 years. The median hearing level thresholds were compared with the predicted values for otologically healthy individuals, which were obtained from British Standards Institute BS 6951.33 The comparison revealed that the median hearing threshold values of the divers lay between the predicted median and predicted upper quartile values. Within the older group (≥40 years), the median and predicted median values of the divers were similar. The author postulated that these results are contrary to the results found in the work by Molvaer et al28 and that the divers in his study had no impairment of the inner ear function compared with a nondiving control group.

The data collected in our study has the advantage that the subject group of divers and the control group of nondivers had similar noise exposure histories. Three divers were excluded from the study because of a history of IEB. None of the divers included in the subject group had a history of IEB, and this can be excluded as a possible cause of any deterioration of inner ear function detected. Pure-tone audiometric thresholds did not reveal significant differences between divers and controls in all groups. However, there were marked interindividual differences in the hearing levels in each age group, so with increasing SDs, the power of our statistical comparison was reduced.

We were only able to assess 64 sport divers and 63 control subjects for our study, with the result that the group size in our study was too small to guarantee a strong statistical power in each age group, especially in the high frequencies where the SD is 15 and more. To guarantee significance with a strong statistical power at all frequencies compared would have required more subjects in each
age group. To find a difference of 10 dB in the hearing levels between 2 groups, presuming that the SD is 15 and more, and to reach a power of 90% at a significance level of 5%, a group size of at least 90 persons in each age group would be necessary. Altogether we would have had to investigate 270 divers and 270 control subjects.

It was difficult to find 64 sport divers who would come at their own expense to our hospital, and it would be very difficult to increase the number of subjects. We reached a power of 90% in age group 1 in 6 of 7 frequencies and in age group 2 in 5 of 7 frequencies. In age group 3 in 3 of 7 frequencies, we had a power of 90%, and in 2 of 7 frequencies, a power of 75%. Only in 2 frequencies (6 and 10 kHz), the power was reduced to 40%. Regarding the costs of a study with 540 subjects to reach a 90% power in each frequency in each age group, we think that we have a good compromise between cost and outcome.

In most of the frequencies, we had an adequate statistical power, and we did not find a significant difference of the hearing levels between sport divers and control subjects at any frequency.

CONCLUSIONS

We did not find statistically reduced hearing levels in sport divers compared with a nondiving control group. The reduced hearing levels of professional divers found in other studies are probably due to the high noise levels that they have to deal with or may be a result of inner ear accidents.

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REFERENCES

2. Strutz J. Otorhinolaryngologic aspects of diving sports. HNO. 1993;41:401-411.

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