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Hearing symptoms and audiometry in professional divers and offshore workers

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Aims The aims are to compare hearing loss between professional divers and offshore workers and to study whether hearing loss symptoms reflected physical disorder. A secondary objective was to study total threshold shift assessment as a method of detecting noise-induced hearing loss (NIHL).

Methods Participants (151 divers and 120 offshore workers) completed a questionnaire for symptoms and screening audiometry. Audiograms were assessed for total threshold shift at 1, 2, 3, 4 and 6 kHz and the prevalence of referral (within population 5th centile) or warning levels (within population 20th centile) of hearing loss. Audiograms were assessed for an NIHL pattern at four levels by two occupational physicians.

Results Hearing loss symptoms were commoner in divers at all levels of hearing loss regardless of differences between groups on audiometry. Hearing loss in offshore workers was within the population age-adjusted norm. Thirteen per cent of divers were within the 5th percentile for threshold shift for the population norm in contrast to 4% of offshore workers and this was predominantly left sided (OR 3.16, 95% CI 1.13–8.93). This difference was lost after adjustment for history of regular exposure to explosion or gunfire. Divers were more likely to have a pattern of severe NIHL on the left (OR 4.61, 95% CI 1.39–15.39, $P < 0.05$). Approximately 50% of participants with severe NIHL did not have a referral level of hearing loss.

Conclusions Divers suffer more NIHL than a control population. Current guidance on the assessment of total threshold shift for the detection of significant NIHL was inadequate in the sample studied.

Key words Diving; health screening; noise-induced hearing loss; somatising.

Introduction

There are reports of occupation-related hearing disorder in professional divers. Two groups have identified a high prevalence of hearing loss in professional divers associated with frequent diving [1,2] and greater than normal age-related deterioration [3]. These studies, however, made little attempt to define the cause of the hearing loss observed. Professional diving involves several factors that can cause otological damage with hearing loss and this might lead to the assumption that diving could cause long-term hearing loss. Many activities undertaken in the course of diving involve exposure to noise [4]. Divers are also subject to inner and middle ear barotrauma resulting from pressure change. This can result in sensorineural hearing loss and some of the hearing loss in divers has been attributed to barotrauma [3], which has been taken to explain the occurrence of unilateral hearing loss. Divers are also at risk of inner ear decompression sickness and this too can give rise to unilateral hearing loss [5,6]. Finally, there is a risk of otitis externa, often caused by *Pseudomonas aeruginosa* infection, in saturation divers. In spite of these factors, UK divers are required only to have a fitness to work assessment of hearing ability and there is no statutory programme of health surveillance.

A questionnaire study of UK professional divers found that divers reported impaired hearing more frequently than control [7]. This may confirm previous work but divers were more likely to report symptoms of all kinds without a strong indication of any associated illness and this made the observation of uncertain value. Accordingly, we conducted a study using screening audiometry to determine whether symptom reporting reflected observable physical disorder and to attempt to gain insight into the mechanism of hearing loss by assessment of patterns of hearing loss on audiometry.

The standard method for assessing screening audiometry data in the UK [8] calculates the total threshold shift

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across five frequencies for each ear (1, 2, 3, 4, 6 kHz), which is assessed against a population norm. This method can fail to detect noise-induced hearing loss (NIHL) and the study design chosen allowed its comparison with medical assessment of audiograms.

Methods

Participants were age-matched male professional divers and non-divers. Divers had a professional diving certificate registered with the UK Health & Safety Executive before 1991. Non-divers were oil and gas industry offshore workers who had undergone a fitness to work medical examination between 1990 and 1992 and had never dived. To reduce survivor bias, participants included men both currently working and retired. Participants were randomly selected from groups of 1035 offshore workers and 1540 professional divers who had previously completed a health questionnaire study [7]. In order to achieve an ~10% sample of the study population, 517 offshore workers and 386 divers were contacted.

Prior to audiometry, participants were screened for hearing loss risk factors. Tobacco smoking is a probable risk factor for hearing loss [9,10] and was recorded as pack years.

A hearing symptom questionnaire established the presence of symptoms of impaired hearing at four levels (not at all, slight, moderate and severe), the presence or absence of any difficulty with hearing, difficulty with the direction of sounds, having the radio or television louder than other family members and hearing noises in the ears. A summary score was then constructed to give a hearing symptoms score of from 0 to 7. There was adequate internal consistency in this score to allow comparison between groups (Cronbach's alpha 0.75).

Automatic audiometry (ASRA 2001, GM Instruments Ltd calibrated to BS EN 60645-1) was used to perform threshold hearing tests at 1, 2, 3, 4, 6 and 12 kHz in a sound proof booth. Data were assessed by adding the hearing thresholds (1–6 kHz) in decibels (dB) for each ear. A figure for total reduction in hearing threshold was calculated by adding the right and left ear total threshold values. An average was also taken for each ear over the five frequencies measured and a significant reduction in thresholds was taken as a mean of ≥20 dB in either ears. Thresholds were then graded in relation to an age-adjusted population norm [8] for hearing within the 20th percentile (warning level) or 5th percentile (medical referral required). Categorical outcome variables for threshold shift were taken at four mutually exclusive levels: <20 dB mean absolute shift in both ears, ≥20 dB mean absolute shift in either or both ears but not at referral or warning level, warning level in either or both ears but not at referral level and referral level in either or both ears.

There is no noise exposure data for either of the two groups studied. Accordingly, in order to assess the degree of exposure to noise, we assessed audiograms for the degree of NIHL pattern change as a surrogate. Two consultant occupational physicians familiar with audiometric screening in occupational health independently read all the audiograms without the knowledge of participant details. Inter-observer variability was assessed by calculating Cohen's kappa for the data obtained and differences were then settled by consensus. Each ear was classified separately. Any single threshold >15 dB greater than normal for the individual's age was classed as abnormal using ISO 7029:2000 normative values. Abnormal audiograms were defined as consistent with no, mild, moderate or severe NIHL using the following criteria selected to identify typical patterns of NIHL:

mild, high-tone threshold >15 dB but <30 dB greater than normal with evidence of recovery of 10 dB rise at higher frequencies from lowest recorded threshold;
moderate high-tone threshold >30 dB greater than normal with step reduction between two adjacent frequencies of ≥15 dB and
severe high-tone threshold ≥50 dB greater than normal with step reduction between two adjacent frequencies of ≥15 dB.

Discrete variables were assessed using chi-square tests and continuous variables were assessed using Mann–Whitney *U*-test or Student's *t*-tests as appropriate. The relationship between prevalence of threshold shift at four levels and group membership was assessed in an unadjusted multinomial logistic regression model. A stepped model was then used to adjust for hearing loss risk factors with an entry probability of 0.05 and a removal probability of 0.25. Risk factors were taken as age (years), cigarette habit (pack years), decompression illness (yes/no), ear infection (yes/no), ear injury or tympanic perforation (yes/no) regular exposure to gunfire or explosions (yes/no) and loud leisure activities (yes/no). The relationship between audiogram abnormality and group membership was assessed at five levels for each ear using an unadjusted multinomial logistic regression model.

SPSS version 14.0 (SPSS Inc. Chicago, IL) was used for analyses. The level for statistical significance was taken as $P < 0.05$. The study received a favourable opinion from the Grampian Region Joint Ethics Committee. Participants provided explicit consent before being entered into the study.

Results

Of the people contacted, 120 offshore workers (23%) and 151 divers (39%) agreed to come in for testing. The two groups were similar in terms of lifestyle (Table 1).

Divers had worked in different sectors of the industry: offshore (62%), coastal and inshore (78%), shellfish

Table 1. Characteristics of divers and offshore workers

	Divers (n = 151), n	Offshore workers (n = 120), n	P
Age, mean (95% CI)	46.9 (45.7–48.2), n = 151	46.3 (44.9–47.7), n = 120	NS
Cigarette pack years, median (IQR)	0.6 (0.0–12.5), n = 150	0.0 (0.0–20.0), n = 119	NS
Units of alcohol per year, median (IQR)	612 (240–981), n = 148	480 (210–956), n = 116	NS
BMI (kg/m^2), mean (95% CI)	27.6 (27.0–28.2), n = 150	27.6 (26.7–28.4), n = 120	NS
Years as a diver or offshore worker, mean (95% CI)	17.3 (16.0–18.6), n = 150	16.5 (15.3–17.7), n = 120	NS
Employment status, % (n), n = 271			
Still working as a diver or offshore worker	47 (74)	80 (89)	<0.001
Other employment	35 (53)	6 (7)	NS
Employed	89 (133)	87 (104)	
Unemployed	2 (3)	3 (4)	
Not working—on sickness benefit	0 (0)	3 (3)	
Retired	9 (14)	8 (9)	
Retirement status, % (n), n = 271			
Not due to illness	6 (9)	4 (5)	NS
Due to ill-health—caused by diving	1 (2)	0	
Due to ill-health—unrelated to diving	2 (3)	3 (4)	
Auditory risk factors, % (n), n = 271			
Ear infection	68 (103)	25 (30)	<0.001
Regular exposure to gunfire or explosions	35 (53)	6 (7)	<0.001
Ear injury or perforated ear drum	27 (40)	9 (11)	<0.001
Loud leisure activities	85 (56)	47 (39)	<0.01
Decompression illness	20 (13)	0	<0.001

BMI, body mass index; IQR, interquartile range; NS, $P \geq 0.05$.

(19%), scientific (17%), police (29%), media (16%), recreational instruction (22%), military (23%) and other (8%). Fifty per cent of divers had worked in two or more sectors. Surface-orientated air diving was reported by 143 divers [median number of dives 968, interquartile range (IQR) 480–2000], 59 reported surface-orientated mixed gas dives (median 12 IQR 5–36) and 64 reported saturation diving (median number of days 500, IQR 168–1090). There was no difference between the groups for family history, exposure to ototoxic drugs, illnesses affecting hearing, recent upper respiratory tract infection or recent exposure to loud noise. Other risk factors differing between groups are indicated in Table 1.

Hearing symptoms and total threshold shift results are summarized in Table 2. Divers more commonly reported hearing symptoms and had a higher hearing symptom score whether or not there were abnormalities on audiometry.

The prevalence of threshold shift change is summarized in Table 3. Hearing in offshore workers was within accepted age-adjusted norms but, although there were no differences in the degree of milder hearing loss, divers were more likely to fall within the 5th percentiles for threshold shift in an unadjusted logistic regression model. After adjustment for hearing risk factors, however, this relationship was lost (OR 1.89 95% CI 0.60–5.95) and, together with age, only a history of regular exposure to explosions or gunfire was significant (OR 4.20 95% CI 1.49–11.49, $P < 0.01$) at the referral level. The prevalence of a referral level of threshold shift on the right side

Table 2. Levels of hearing symptoms and audiometry summary variables in divers and offshore workers

	Divers	Offshore workers	P
Symptom score for all levels of threshold shift	1, 0–3	0, 0–1	<0.001*
Symptom score excluding referral levels of threshold shift	1, 0–2	0, 0–1	<0.01*
Symptom score excluding severe NIHL pattern on audiometry	1, 0–3	0, 0–2	0.001*
Any symptom of impaired hearing, n (%)	93 (62)	48 (40)	0.001**

$P < 0.05$ for significance: Mann–Whitney U-test*, chi-square test**. Hearing loss symptom scores are summarized as the median and interquartile range.

was the same in divers as in offshore workers but, on the left, it was commoner in divers than in offshore workers ($P < 0.01$). A referral level of left-sided hearing loss was seen in seven (22%) of recreational instructor divers ($P < 0.05$ chi square) and there were no other significant associations with diving sector.

The prevalence of an NIHL audiogram pattern is summarized in Table 4. Inter-observer variability was good to very good (Cohen's kappa 0.64–0.92). There were no differences between groups for the right ear but a left ear audiogram compatible with severe NIHL was commoner in divers. Severe left-sided hearing loss was seen in eight (25%) recreational instructor divers ($P < 0.05$ chi square)

Table 3. Prevalence of threshold shift changes in divers and offshore workers

	Divers		Offshore workers		Unadjusted OR	
	n (%)		*n* (%)		Mean, 95% CI	*P*
Mean shift <20 dB	78 (52)		65 (55)		reference	
Mean shift ≥20 dB	25 (17)		32 (27)		0.65, 0.35–1.21	NS
Warning (20th %)	27 (18)		16 (14)		1.41, 0.70–2.83	NS
Referral (5th %)	19 (13)		5 (4)		3.16, 1.13–8.93	<0.05
Number of referral audiograms by side, *n* (%)	Left 15 (10)	Right 7 (6)	Left 5 (3)	Right 2 (2)		

ORs are for the chances of having the condition associated with being a diver from an unadjusted multinomial regression model with participants having <20 dB mean threshold shift as the reference group.

Table 4. Prevalence of audiogram abnormalities in divers and offshore workers

	Divers	Offshore workers	Unadjusted OR	*P*
	n (%)	*n* (%)	Mean (95% CI)	
Normal left	58 (39)	50 (42)	reference	
Right	72 (48)	58 (49)	reference	
Mild left	23 (15)	22 (19)	0.90 (0.45–1.81)	NS
Right	16 (11)	17 (14)	0.76 (0.35–1.63)	NS
Moderate left	24 (16)	17 (14)	1.22 (0.59–2.51)	NS
Right	21 (14)	11 (6)	1.54 (0.69–3.45)	NS
Severe left	17 (11)	4 (3)	3.66 (1.16–11.61)	0.03
Right	11 (7)	8 (7)	1.11 (0.42–2.93)	NS
Other left	27 (18)	25 (21)	0.93 (0.48–1.81)	NS
Right	29 (19)	24 (20)	0.97 (0.50–1.85)	NS

ORs are for the chances of having the condition associated with being a diver. NS, $P \geq 0.05$.

and there were no other significant associations with diving sector.

NIHL scores correlated significantly with threshold shift both on the left (Pearson correlation coefficient 0.574, $P < 0.001$) and right (Pearson correlation coefficient 0.597, $P < 0.001$) (Figure 1). In spite of this, 12 of 19 audiograms with a severe right-sided NIHL pattern and 9 of 21 left-sided audiograms in the same category did not fall into the medical referral levels for threshold shift (Table 5). Audiograms with a non-NIHL abnormality had a mild to moderate degree of threshold shift (Figure 1, Table 5).

Discussion

Symptoms of hearing impairment were commoner in divers and this confirmed the observation made in an earlier study on the same population [7]. Divers were more likely to have a left-sided referral level of threshold shift and a severe NIHL pattern also on the left. This might seem to support a relationship between symptom reporting and hearing loss in divers. Divers, however, were also more likely to report symptoms at levels of hearing loss which were the same in both groups (Table 2). UK divers from this population were found to be more likely than control to report symptoms of any kind [7] and this tendency is reflected here rather than entirely indicating the difference in observable hearing loss. Other work suggests that the discrepancy between symptoms of hearing impairment and abnormalities on audiometry might be used as a measure of psychosocial pressure or somatising in a workforce [11].

This study demonstrated that while offshore workers' hearing was within a population norm, divers were more likely to have abnormal hearing since 13% had a degree of hearing loss expected in only 5% of the norm. Divers were not only more likely to have significant hearing loss than controls but were also more likely to depart from the population norm. This may be seen as reassuring for offshore workers while indicating a cause for concern in divers. There was, however, an indication on audiometry assessment, of some degree of NIHL in ~50% of both populations indicating that a reduction in noise exposure would benefit both groups.

Divers are exposed to hearing loss risk factors specific to diving, including otic barotraumas, decompression illness and otitis externa and there has been concern that these result in poorer hearing in this group. In this study, however, greater hearing loss was associated with a pattern of severe NIHL in divers and reported regular exposure to gunfire and explosions with no difference in the prevalence of other patterns of hearing loss on audiometry between groups. This may be taken as evidence that, while some diving-related events have the potential to damage hearing, exposure to noise is more important in this occupational group. On the other hand, diving-associated otic barotraumas have been related to a high-tone hearing loss [12] and this may be misinterpreted as a pattern of NIHL on audiometry. If this were the case, the effect of otic barotraumas would be underestimated. Another case series, however, describing audiograms in 31 cases of inner ear disorder caused by atmospheric pressure change, found that high-tone hearing loss in isolation

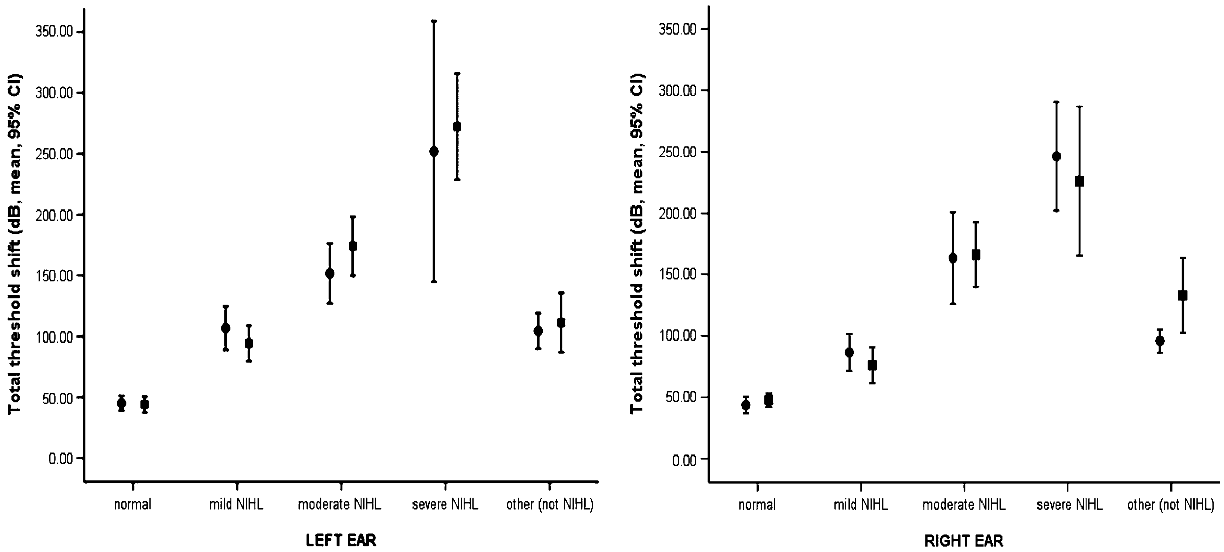

Figure 1. Relationship between total threshold shift at 1, 2, 3, 4 and 6 kHz in the right and left ears with clinical assessment scores for an NIHL pattern on clinical assessment of audiograms; solid circles, offshore workers; solid squares, divers.

Table 5. Threshold shift assessment of hearing loss tabulated against clinical assessment

Clinical assessment	Threshold shift assessment			
	<20 dB	≥20 dB	Warning	Referral
Normal				
Right	105	17	6	2
Left	98	8	1	1
Mild NIHL				
Right	14	13	5	1
Left	18	20	5	2
Moderate NIHL				
Right	1	7	17	7
Left	3	11	21	6
Severe NIHL				
Right	0	2	10	7
Left	0	0	9	12
Other not NIHL				
Right	23	18	5	7
Left	24	18	7	3

<20 dB, less than 20 dB mean absolute threshold shift; ≥20 dB, equal or more than 20 dB mean absolute threshold shift; warning, threshold shift falling within the age corrected 20th centile but not referral; referral, threshold shift falling within the age corrected 5th centile.

was unusual [13] and its finding after a diving accident may reflect pre-existing problems [6]. Further, reported ear injury or infection were not associated with hearing loss in this study. The concept that hearing loss is not associated with diving-related events is also supported by the absence of hearing loss in groups of recreational divers [14,15].

Unilateral left-sided loss in divers has been taken as evidence of pressure change-related damage to the ear either caused by barotrauma or decompression illness [3] and the data from this study indicated that hearing loss in divers was left sided. Progressive left-sided deafness, however, also occurs in populations not exposed to decompression illness or barotraumas [16–19]. Divers may gain their initial training in the military and 22% of those studied here reported experience of military diving. Also, regular exposure to gunfire or explosions was associated with hearing loss in this study. When guns are fired from the right shoulder, the impulse noise is directed more to the left than the right and this has been assumed to underlie left-sided hearing loss in the military. The subject has been reviewed by Job *et al.* [20] who also conducted a study on right and left eye-dominant shooters in the French Army who were permitted to shoot from their preferred shoulder. There was hearing loss at 6–7 kHz in both groups but always more marked on the left, no matter from which shoulder the gun was fired, suggesting that the left cochlea is more sensitive to NIHL than the right. There is a significant level of adverse noise exposure from diver helmets [21] and left-sided hearing loss might attributed to the positioning of the gas inlet or communications earpiece. This study, however, does not support helmet noise as a cause of hearing loss since left-sided hearing loss was significantly associated with working as a recreational diving instructor and helmets are only rarely used in this sector.

Guidance to The Control of Noise at Work Regulations 2005 method of analysing audiometry data was used to identify participants falling within the 20th and 5th centiles [8]. It is recommended that a warning regarding hearing loss and protective action is given to people falling within the 20th centile and that medical referral is required for hearing loss within the 5th centile. Although numbers were small at these levels of hearing, this method of analysis failed to indicate medical referral for ~50% of participants thought to have a severe pattern of NIHL of interest to an occupational physician (Table 5). NIHL is first indicated on audiometry by a reduction in threshold at 4–5 kHz, which, as the damage worsens, becomes greater and moves into the lower frequencies. Analysis of threshold shift across all frequencies may not detect hearing loss at those indicating an NIHL pattern until there is a major effect or the damage moves into the lower frequencies. Similar observations have been made elsewhere [22] and more sensitive markers for the prediction of significant levels of hearing loss were suggested. Since a warning level of hearing loss would have detected 90% of cases of interest, it may be a more appropriate referral level. The current referral level seems to be inadequate for detecting a degree of NIHL considered severe on audiometry assessment by occupational physicians.

This study may be considered to have weakness and strengths. Its cross-sectional design does not allow attribution of cause and a retrospective assessment of risk factors for hearing loss is prone to bias, especially in a population with a tendency to over-report symptoms. The main purpose of the study, however, was to use examination to clarify the degree to which symptom reporting reflected physically identifiable disorder. Another disadvantage of the study design was the inability to distinguish whether the hearing loss measured happened in association with work as a diver or offshore worker or before or after such work. The use of a control group, however, allowed an association to be made between work as a diver and more symptoms and greater prevalence of significant hearing impairment. Although we did not detect hearing loss caused specifically by diving-related injury in the group studied, this should not be taken as an indicator that it does not happen; clearly, it is possible. It is equally possible to have a workforce in which these risk factors are of less importance than a predominant noise effect: as is suggested by this study. The groups studied were randomly sampled from the background population but there may have been a degree of responder bias since divers were more likely to experience symptoms without objective hearing loss. This factor, however, would have attenuated any differences on audiometry between groups. Also, the level of hearing impairment symptoms in the groups studied was very close to the parent population of the questionnaire study [7]. A major strength of the study lay in the blinded scoring of audiogram pattern for NIHL, which allowed an assessment of the analysis method recommended for audiometry screening in the UK.

In summary, while hearing in offshore workers was within the population norm, divers were more likely to fall within the 5th centile for threshold shift and to have a left-sided pattern of severe NIHL, probably due to exposure to noise. Divers were also more likely to report hearing loss symptoms partially due to a tendency in divers to over-report symptoms or somatise. Scoring hearing loss by assessment of threshold shift failed to detect ~50% of people thought to have severe NIHL by medical assessment indicating that current guidance on the assessment of screening audiograms is in error.

Key points

- While offshore workers fell within population norms for hearing loss on audiometry, divers were more likely to fall within the 5th centile for threshold shift and to show a pattern of severe noise-induced hearing loss indicating that diving is more associated with hearing loss due to noise exposure rather than other diving-related factors.
- Divers were more likely to have symptoms of hearing loss than offshore workers regardless of differences between groups on audiometry and this indicates some somatising in divers.
- Current UK guidance on methods for assessing noise-induced hearing loss by screening audiometry seem to be inadequate and, in this study, failed to detect 50% of severe noise-induced hearing loss as judged by a clinical assessment of the audiogram.

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Conflicts of interest

None declared.

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