

# The absence of hearing loss in otologically asymptomatic recreational scuba divers.

D. McD, TAYLOR<sup>1</sup>, J. LIPPMANN<sup>2</sup>, D. SMITH<sup>3</sup>

<sup>1</sup>Director of Emergency Medicine Research, Emergency Department, Royal Melbourne Hospital, Victoria, Australia; <sup>2</sup>Executive Director, Diver Alert Network (DAN), S.E. Asia-Pacific; <sup>3</sup>Audiologist, Vicdeaf, Victoria, Australia

Taylor D. McD, Lippmann J, Smith D. The absence of hearing loss in otologically asymptomatic recreational scuba divers. *Undersea Hyperb Med* 2006; 33(2):135-141. We undertook a retrospective cohort study of 16 experienced recreational scuba divers and 16 matched non-diver controls to determine the prevalence of hearing loss and, if present, the likely causes of this loss. Each subject was required to be aged 55 years or less and to have no history or likelihood of hearing loss. An audiologist, blinded to each subject's group status, undertook all examinations. There were no significant differences in group demographics. All divers were highly experienced (median number of dives 725). Comparison of mean hearing thresholds (range 250-8000 Hz) revealed no significant differences between divers and non-divers for both air and bone conduction studies. The only exception was at 6000 Hz where the air conduction threshold was significantly higher in divers than in non-divers ( $p=0.03$ ). However, there were no significant differences in Pure Tone and High Frequency averages. We conclude that experienced recreational scuba divers do not have elevated hearing threshold levels overall when compared to non-diver controls. This conclusion differs from that of investigators who have examined the hearing of experienced professional divers. Further investigation is indicated to further investigate this discrepancy and to determine whether the apparent hearing loss among the divers at 6000Hz was an isolated departure from normal hearing thresholds or, in fact, the result of diving.

## INTRODUCTION

Most reports of diving injury have concentrated on acute injuries rather than chronic disability e.g. deafness. One recent study involved 709 experienced, recreational divers in Australia and the US. The Australian cohort was asked to report *any* existing medical conditions, not necessarily those caused by diving. Within this cohort, an unexpected high prevalence of aural disorders was found: 12.2% and 23.4% of divers reported past or present hearing loss and tinnitus, respectively (1). However, among both cohorts, only 1.4% reported a chronic aural problem that they *directly* attributed to diving. Hence, while many divers reported aural symptoms, few attributed them to diving. It is possible that repeated hyperbaric exposure among very experienced divers may be responsible for their

aural symptoms, despite the lack of an obvious acute injury for many.

The cause(s) of the aural disorders described above are unknown. Edmonds has reported that hearing loss in divers may be due to external ear canal obstruction, tympanic membrane perforation, middle ear disorders and sensorineural hearing damage (2). However, aural barotrauma is the most likely cause (as it is a relatively common occurrence). It is known that the strain exerted upon the tympanic membrane (TM) and middle ear from minor barotrauma results in reversible impairment of the recoiling capacity of the TM elastic fibrils. It has been postulated that, if this barotrauma is repeated over lengthy periods, the TM changes could become irreversible (3). Hence, hearing loss is a possible outcome.

Sub-clinical brain and inner ear injury may offer an alternative explanation. There

is some evidence that divers may suffer sub-clinical pathological deficit even in the absence of a history of clinical DCI or other diving accident (4-7). Reul et al (6) found that divers had significantly more hyper-intense lesions of the sub-cortical cerebral white matter (on MRI) compared to controls. Although selection bias may have influenced that study, the authors concluded that long term recreational diving may cause CNS degeneration even if diving incidents have not occurred. The exact mechanism of this degeneration remains unclear although both sub-clinical DCI (6) and paradoxical gas embolism, through a patent foramen ovale, have been postulated (8).

Regardless of the exact mechanism, repeated exposures to hyperbaric environments and breathing compressed gas for prolonged periods may impair physical and psychological health (5). However, this impairment may or may not be noticeable to the individual. We aimed to compare the hearing of a cohort of experienced recreational scuba divers with that of a cohort of non-diver controls. If hearing loss is demonstrated among the divers, we aimed to determine if this loss was conductive (likely barotrauma related) or sensorineural (barotrauma or DCI related) in nature.

## **METHODS**

This was an historical cohort study of divers and matched non-diver controls. It was undertaken in the Acoustic Laboratory, Department of Speech Pathology and Audiology of the Royal Melbourne Hospital (RMH) in January through December 2003. It was authorized by the RMH Human Research Ethics Committee and all subjects gave written informed consent.

Sixteen experienced, recreational scuba divers and sixteen non-diver controls were enrolled. Subjects were eligible for enrollment if they were aged 18-55 years. Also, the divers were required to have logged at least 250 dives.

Subjects were excluded if they had a history of aural disease (hearing loss, tinnitus, vertigo, middle or inner ear injury or surgery), existing aural disease (infection, recent barotrauma with residual pain or hearing impairment), or a risk factor for hearing loss (relevant neurological disease, material occupational or leisure noise exposure as defined by Lutman (9), neurological decompression illness). They were also excluded if examination revealed ear canal obstruction, or an abnormal tympanic membrane, tympanogram, cranial nerve, or sharpened Romberg's test.

Divers were recruited from Melbourne scuba diving clubs and the Divers Alert Network (DAN), an international organization dedicated to scuba diving research, safety and education. Contact was made with potential subjects using representation at club meetings and personal invitation. The sixteen matched non-divers were recruited from RMH staff and acquaintances of the study investigators. Where possible, each diver was matched to a non-diver of similar age, gender and nature of usual employment (blue collar/trade, white collar/clerical, professional [tertiary education]).

One investigator (DT) undertook all screening (history and medical) examinations. Another investigator (DS), blinded to the status of the subject (diver or non-diver), undertook all audiometry examinations. Tympanometric measurements and pure-tone thresholds were obtained using a Grason-Stadler (Littleton, MA, USA) GSI-33 Middle Ear Analyzer and GSI-16 Audiometer, respectively. Both machines had been independently calibrated prior to the study by Hearing Conservation Services of Australia Pty Ltd. Audiometry examination determined air and bone conduction hearing threshold levels (decibels) across a range of 250 to 8000 Hz frequencies (6000 and 8000 Hz frequencies are routinely omitted in bone conduction testing). The mean group (diver and non-diver) hearing threshold levels, at each frequency,

were then calculated. These were the mean of the values for both ears for all subjects in the group. Finally, Pure Tone Averages (PTA, mean of 500, 1000 and 2000 Hz hearing thresholds) and High Frequency Averages (HFA, mean of 1000, 2000 and 4000 Hz hearing thresholds), for air and bone conduction, were calculated for each group.

The sample size calculation was based upon the premise that the effect of repeated hyperbaric exposure on hearing thresholds was a cumulative dose/response condition. Hence, if hearing loss existed among the divers, it was likely to be a small amount in many divers rather than a considerable amount in very few divers. We determined that a difference between the groups of one standard deviation in hearing threshold (approximately 6 db) would be clinically significant. Therefore, we needed to enroll 16 divers and 16 controls to have an 80% power to demonstrate this difference, if it existed (level of significance 0.05). The two groups were compared statistically using Fisher's exact test (for proportions) and the unpaired, 2-sided, t-test (for continuous, normally distributed data). SPSS for Windows software (version 12.0.1, SPSS Inc., Chicago, Illinois) was used for all analyses.

## RESULTS

Table 1 describes the demographics of the two subject groups. The groups were well matched for gender and age. Although there were more professionals (subjects with a tertiary education) in the non-diver group, the overall distributions of employment status within the groups did not differ significantly. The many years of diving and the large number of dives done indicate clearly that the divers were highly experienced in their sport.

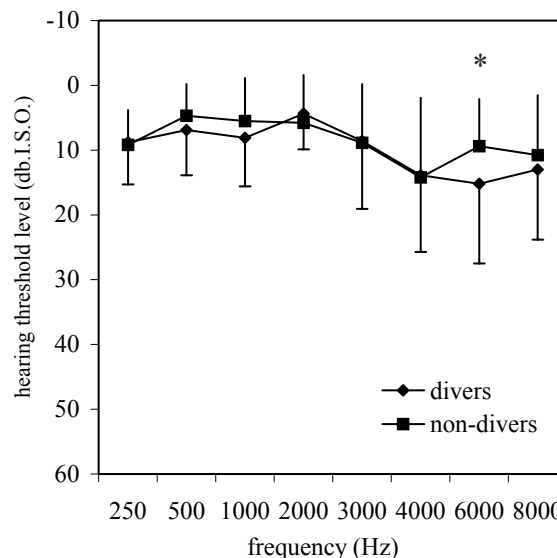
**Table 1.** Demographics of diver and non-diver subject groups

	divers (n=16) n (%)	non-divers (n=16) n (%)	p value
gender			1.00
male	13 (81.3)	13 (81.3)	
female	3 (18.8)	3 (18.8)	
mean age (years)	39.9 ± 10.9	36.9 ± 7.3	0.37
usual employment			0.05
blue collar / trade	1 (6.3)	0 (0.0)	
white collar / clerical	7 (43.8)	2 (12.5)	
professional*	8 (50.0)	14 (87.5)	
years of diving			
mean ± SD	16.1 ± 9.0	na	-
median (range)	15 (4-32)	na	-
number of dives			
mean ± SD	1347.5 ± 1834.2	na	-
median (range)	725 (500-8000)	na	-

\*occupations requiring a tertiary education

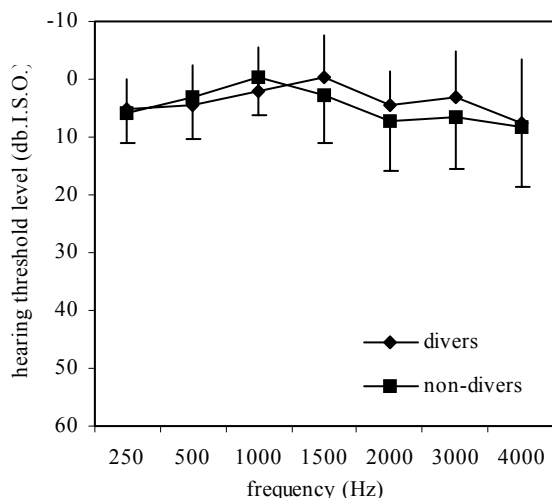
Figure 1 describes the mean air conduction hearing threshold levels for the two groups. At most frequencies, the thresholds did not differ significantly (NS) between the groups. The only exception was at 6000 Hz where the diver threshold was significantly higher than the non-diver threshold (p=0.03). Figure 2 describes the mean bone conduction hearing threshold levels for the two groups. At all frequencies, the thresholds did not differ significantly (NS) between the groups.

**Fig 1.** Mean air conduction threshold levels of divers and non-divers (mean ± SD)



\* significant difference between the two groups (p=0.03)

**Fig. 2.** Mean bone conduction threshold levels of divers and non-divers (mean ± SD)



\* thresholds not measured at 6000 and 8000 Hz

Table 2 describes the air and bone conduction PTAs and HFAs for both groups. With the exception of bone conduction HFA, the average thresholds for the diver group were higher than the non-diver group. However, these differences were small and not statistically significant. For both groups, as expected, the air conduction averages were marginally higher than the bone conduction averages.

**Table 2.** Air and bone conduction Pure Tone and High Frequency Averages

threshold averages	divers (n=16)	non-divers (n=16)	p value
Air conduction (mean ± SD)			
Pure Tone Average <sup>‡</sup>	6.4 ± 5.7	5.3 ± 5.5	0.44
High Frequency Average <sup>§</sup>	8.6 ± 6.1	8.5 ± 7.1	0.96
Bone conduction (mean ± SD)			
Pure Tone Average <sup>‡</sup>	3.8 ± 5.6	3.6 ± 6.1	0.90
High Frequency Average <sup>§</sup>	4.7 ± 5.4	5.3 ± 6.8	0.71

<sup>‡</sup> average of 500, 1000 and 2000 Hz frequencies  
<sup>§</sup> average of 1000, 2000 and 4000 Hz frequencies

## DISCUSSION

Recreational scuba diving is a popular leisure sport (10) with an estimated 9 million certified divers in the United States of America (US) alone (11). Diving has been described as

a high risk sport (12-14), and Edmonds (15) quotes international reports of death rates among recreational divers of 15-20 deaths per 100,000 divers. Diving-specific acute injuries, including decompression illness (DCI) and the various forms of barotrauma, have been well described (13, 16-19). Specific chronic effects of diving, including dysbaric osteonecrosis and residual deficit following DCI and arterial gas embolism (AGE), have also been reported (4, 5, 20).

It is well recognized that acute diving injuries may result in permanent hearing loss (2). Acute barotrauma, a common injury, can affect the middle ear to cause conductive deafness or the inner ear to cause residual cochleovestibular deficits (2, 21, 22). In a review of barotrauma-induced hearing loss, Talmi *et al.* reported that middle and inner ear barotrauma were major causes of diving-induced hearing loss (23). Inner ear DCI also carries a high risk of residual ear damage, even despite hyperbaric oxygen recompression therapy (22). In a second review, Talmi *et al.* reported that otologic DCI is also an important cause of diving-induced hearing loss (24).

The association between diving and hearing loss, in the absence of clinically apparent diving injury, may not be as clear-cut. Most reports that have examined diving and hearing loss have examined professional divers and these reports describe a range of findings. Among the most important was that of Edmonds who examined the hearing of 28 professional abalone divers and found a significant sensorineural, high frequency deafness in over 60% (25). Molvaer and Lehmann, in a study comparing the hearing thresholds of professional divers with normality curves (26), reported that the divers' thresholds were elevated in the high frequencies in all age groups. In a subsequent study, Molvaer and Albrektsen re-examined the hearing thresholds of 116 professional divers after a 6 year

period and concluded that the divers' hearing deteriorated faster than that of otologically normal subjects (21). However, not all studies have been as conclusive. Sharoni et al. found the average pure tone hearing thresholds of 13 asymptomatic professional divers to be slightly but significantly higher than those of 12 non-divers (27). Finally, Skogstad *et al.*, in a study of 54 young professional divers, found no change in hearing thresholds over a 3 year follow up period (28) and no statistical difference between the thresholds of 26 experienced construction divers and 26 workshop employed controls (29).

Compared with professional divers, few studies have examined the hearing of recreational divers. Klingmann *et al.* (30), in a study of 60 experienced recreational divers (mean number of dives 650) and 63 non-diver controls found no statistically significant differences in the hearing thresholds of the two groups. Despite considerable exposure to the hyperbaric environment, the divers in our study also appeared to have hearing thresholds that differed little from those of the non-diver controls. This was evident from the lack of significant difference between the PTA and HFA of the two groups. However, the single significant difference between the groups (air conduction at 6000Hz) may represent an important departure from otherwise normal hearing threshold patterns. While it is difficult to attribute this definitively to diving, the finding is consistent with high frequency air conduction hearing loss reported among professional divers (26).

Our study, overall, appears to support the findings of Klingmann *et al.* (30) and suggests that recreational divers who have not suffered acute aural injuries while diving do not appear susceptible to significant generalized hearing loss through their sport. While this finding is encouraging, it should in no way afford complacency among recreational divers.

This is particularly so given the significant air conduction hearing loss among the divers at 6000Hz. Further research is required in order to determine whether this was an isolated finding or, in fact, the result of diving.

The available evidence suggests an apparent difference in risk of hearing loss between professional and recreational divers. This may, in part, result from professional divers having considerably longer and more frequent exposures to the diving environment than their recreational counterparts. However, it has been suggested that considerable levels of noise associated with some professional diving activities may account for the significant hearing loss reported in some studies (21, 26, 28). The finding that the loss among many professional divers is high frequency loss (25, 26) supports this possibility. Noise may also provide an explanation for the apparent difference between professional and recreational divers' hearing thresholds since some professional divers are exposed to considerable occupational noise levels unlikely to be encountered by recreational divers. Presently, however, there is insufficient evidence to support these suggestions. Additional larger studies are indicated to further investigate the hearing of recreational divers and to compare their hearing thresholds to those of professional divers. If differences are confirmed, then the particular risk factors associated with professional diving should be investigated. These factors may include ambient noise levels, demographic characteristics of the divers and dive profiles.

This study has important limitations. Selection bias is possible, as subjects who suspected that they have hearing loss may have been more inclined to volunteer. However, the advertising strategies employed did not indicate initially that the study was an investigation of hearing *per se* and most subjects were prepared to enroll regardless of its nature. Subjects in this study were heavily screened in order to

exclude those at high risk for, or with known, aural disease. Accordingly, this process may have excluded some relevant subjects with symptoms secondary to repeated barotrauma or sub-clinical DCI. This would have tended to decrease the differences between the diver and non-diver groups and lessen the chances of finding hearing threshold differences, if they existed. Measurement bias is unlikely to have affected the results significantly as the study endpoints were objective and measured by an experienced audiologist who was blinded to the nature of each subject's group status. Recall bias during subject screening may have affected results although significant aural or neurological injuries and/or diving accidents are likely to be recalled and reported. Many conditions and experiences associated with hearing loss had the potential to confound the study results. However, the strict exclusion criteria, based upon validated screening criteria, are likely to have minimized these confounders. In particular, hearing loss resulting from aging is not expected prior to the age of 55 years (31). After this age, age-related adjustments are required in the calculation of hearing thresholds. For this reason, subjects were restricted to age 55 years or less. Also, the close matching of controls was also likely to have minimized confounding factors between the groups. Finally, the sample size in this study was relatively small. However, this was calculated using a difference between groups that was considered to be clinically significant. Indeed, the results indicate that there was very little difference between the hearing thresholds of the groups and a larger sample size is unlikely to have affected the conclusions.

In conclusion, this study indicates that recreational scuba diving, in the absence of acute diving injuries, is not associated with clinically significant hearing loss overall. However, we recommend that additional studies of recreational divers be undertaken to further

investigate this issue, especially given the isolated air conduction loss detected at 6000Hz among the divers. The available literature suggests that hearing loss among professional divers is likely to be a real phenomenon and investigations of the variables that may contribute to this loss are indicated.

#### ACKNOWLEDGEMENTS

The authors thank each of the participants in this study and the Audiology Department of the Royal Melbourne Hospital for making their laboratory available for this study. We also acknowledge the Diver Alert Network (SE Asia Pacific) who funded the study.

#### REFERENCES

1. Taylor DMcD, O'Toole KS, Ryan CM. Experienced, recreational scuba divers in Australia continue to dive despite medical contra-indications. *Wilderness Environ Med* 2002; 13(3): 187-193
2. Edmonds C. The ear and diving: hearing loss. In: Edmonds C, Lowry C, Pennefather J, Walker R (Eds) *Diving and Subaquatic Medicine*. 4th ed. London: Arnold Publishers; 2002: 379-384
3. Paaske PB, Staunstrup HN, Malling B, Knudsen L. Impedance measurement in divers during a scuba-diving training programme. *Clin Otolaryngol* 1991; 16: 145-148
4. Walker R, Edmonds C. Long-term effects of diving. In: Edmonds C, Lowry C, Pennefather J, Walker R (Eds) *Diving and Subaquatic Medicine*. 4th ed. London: Arnold Publishers; 2002: 457-464
5. McQueen D, Kent G, Murrison A. Self-reported long-term effects of diving and decompression illness in recreational SCUBA divers. *Br J Sp Med* 1994; 28: 101-104
6. Reul J, Weis J, Jung A, Willmes K, Thron A. Central nervous system lesions and cervical disc herniations in amateur divers. *Lancet* 1995; 345:1403-1405
7. Dutka AJ. Long Term Effects on the Central Nervous System. In: Brubakk AO & Neuman TS (Eds). *Physiology & Medicine of Diving*. 5th ed. London: Saunders ; 2003: 680-699
8. Knauth M, Ries S, Pohimann S et al. Cohort study of multiple brain lesions in sport divers: role of a patent foramen ovale. *BMJ* 1997; 314: 701-705
9. Lutman ME, Davis AC. The distribution of hearing threshold levels in the general population aged 18-30 years. *Audiology* 1994; 33: 327-350
10. Walker R. Medical standards for recreational divers. In: Edmonds C, Lowry C, Pennefather J, Walker R (Eds) *Diving and Subaquatic Medicine*.

- 4th ed. London: Arnold Publishers; 2002: 533-552
11. Diver Alert Network. Report on decompression illness and diving fatalities. Durham, NC: Diver Alert Network, 2000
12. Morgan WP. Anxiety and panic in recreational scuba divers. *Sports Medicine* 1995; 20(6): 398-421
13. Spira A. Diving and Marine Medicine Review Part II: Diving Diseases (review) *J Travel Med* 1999; 6: 180-198
14. Elliott D. Why fitness? Who benefits from diver medical examinations? *SPUMS* 2000; 30: 206-209
15. Edmonds C. Why divers die: the facts and figures. In: Edmonds C, Lowry C, Pennefather J, Walker R (Eds) *Diving and Subaquatic Medicine*. 4th ed. London: Arnold Publishers; 2002: 474-490
16. Edmonds C, Lowry C, Pennefather J, Walker R (Eds) *Diving and Subaquatic Medicine*. 4th ed. London: Arnold Publishers; 2002: 55-182
17. Newton HB. Neurological complications of scuba diving. *Am Fam Physician* 2001;63:2211-8,2225-6
18. Report on decompression illness, dive fatalities and Project Dive Exploration. Durham, North Carolina: Divers Alert Network, 2003
19. Report on decompression illness, dive fatalities and Project Dive Exploration. Durham, North Carolina: Divers Alert Network, 2004
20. British Medical Research Council Decompression Sickness Central Registry and Radiological Panel. Aseptic bone necrosis in commercial divers. *Lancet* 1981; 2: 384-388
21. Molvaer OI, Albrektsen G. Hearing deterioration in professional divers: an epidemiological study. *Undersea Biomed Res* 1990; 17: 231-246
22. Shupak A, Gil A, Nachum Z, Miller S, Gordon CR, Tal D. Inner ear decompression sickness and inner ear barotraumas in recreational divers: a long-term follow-up. *Laryngoscope* 2004; 113: 2141-2147
23. Talmi YP, Finkelstein Y, Zohar Y. Barotrauma-induced hearing loss. *Scand Audiol* 1991; 20: 1-9
24. Talmi YP, Finkelstein Y, Zohar Y. Decompression sickness induced hearing loss. *Scand Audiol* 1991; 20: 25-28
25. Edmonds C. Hearing loss with frequent diving (deaf divers). *Undersea Biomed Res* 1985; 12: 315-319
26. Molvaer OI, Lehmann EH. Hearing acuity in professional divers. *Undersea Biomed Res* 1985; 12: 333-349
27. Sharoni Z, Shupak A, Spitzer O, Nachum Z, Gadot N. Vestibular findings in professional divers. *Ann Otol Rhinol Laryngol* 2001; 110: 127-131
28. Skogstad M, Haldorsen T, Arnesen AR. Auditory function among young occupational divers: a 3-year follow-up study. *Scand Audiol* 2000; 29: 245-252
29. Skogstad M, Haldorsen T, Kjuus H. Pulmonary and auditory function among experienced construction divers: a cross-sectional study. *Aviat Space Environ Med* 1999; 70: 644-649
30. Klingmann C, Knauth M, Ries S, Tasman A-J. Hearing threshold in sports divers. Is diving really a hazard for inner ear function? *Arch Otolaryngol Head Neck Surg* 2004; 130: 221-225
31. MacRae J. Improved Procedure for Determining Percentage Loss of Hearing. National Acoustic Laboratories Report No 118, 1st ed., Canberra, Australian Government Publishing Service. 1988