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Vestibular effects of diving—a 6-year prospective study

Frederik Kragerud Goplen[1], Marit Grønning[2,3], Torbjørn Aasen[1] and Stein Helge Glad Nordahl[1]

Background Permanent injuries to the vestibular end organs may occur in diving due to decompression illness (DCI) or barotraumas. This may lead to distressing long-term symptoms, including dizziness and disequilibrium.

Aims To look for evidence of vestibular disorders in working divers and to relate this to diving exposure or injuries.

Methods A cohort of 67 men aged 28 ± 5 years (mean ± SD) completing a basic course for working divers answered a questionnaire and underwent clinical otoneurological examination, electronystagmography (ENG), including alternate bithermal caloric tests and platform posturography. The procedure was repeated after 3 and 6 years.

Results At follow-up, none of the divers had experienced inner ear barotraumas or inner ear DCI. Two cases of untreated probable DCI were diagnosed retrospectively in 27 232 dives. Middle ear barotrauma was reported by 36%. There was no correlation between diving frequency and postural sway at follow-up. Transient dizziness during or shortly after a dive was reported by 63 and 15%, respectively. The prevalence of dizziness on land and ENG abnormalities did not change during follow-up. No vestibular disorders were diagnosed.

Conclusions Transient vestibular symptoms and middle ear barotraumas are common in diving. This study found no evidence of long-term vestibular effects. Vestibular disorders in divers are probably related to singular events, like inner ear barotraumas or inner ear DCI, rather than frequent diving *per se*.

Key words Balance; barotrauma; decompression illness; inner ear; posturography.

Introduction

Divers occasionally suffer vestibular injury due to barotrauma or decompression illness (DCI) [1–3]. Acute cases are usually recognized by a combination of vertigo, nausea and vomiting with a tendency to fall to the injured side and nystagmus to the contralateral side. The loss of peripheral vestibular function may be permanent, but in spite of this, there is often a nearly complete symptomatic recovery after weeks to months due to central vestibular compensation.

Less dramatic but much more common than the injuries mentioned above are middle ear barotraumas and short episodes of vertigo during diving. Middle ear barotrauma is the most common medical problem in diving [4,5]. It is characterized by ear pain, usually during descent, conductive hearing loss, and otoscopic signs of barotrauma to the middle ear (haemotympanum) or the tympanic membrane (haemorrhage and/or rupture). The prognosis is usually excellent but repeated barotraumas may cause permanent hearing loss [6].

Vertigo while diving is common. Alternobaric vertigo is a short spell of vertigo, which usually occurs during ascent, and is thought to arise because of asymmetric pressure in the middle ears during equalization. The lifetime prevalence in divers has been reported to be close to 30% [7,8]. Other causes of vertigo in diving are inner ear barotrauma, DCI, caloric stimulation, nitrogen narcosis or, in deep diving, the high-pressure nervous syndrome [9].

The question raised in this study is to what extent working divers, because of such events, are at risk of developing chronic vestibular disorders. A recent study

[1]Department of Otolaryngology, Head and Neck Surgery, Haukeland University Hospital, N-5021 Bergen, Norway.

[2]Department of Neurology, Haukeland University Hospital, N-5021 Bergen, Norway.

[3]Department of Occupational Medicine, Haukeland University Hospital, N-5021 Bergen, Norway.

Correspondence to: Frederik Kragerud Goplen, Department of Otolaryngology, Head and Neck Surgery, Haukeland University Hospital, N-5021 Bergen, Norway. Tel: +47 55 97 50 00; fax: +47 55 97 26 43;
e-mail: frederik.goplen@ore.uib.no

showed that vestibular symptoms were more common in retired offshore divers than in age-matched controls [10]. The symptoms were related to a previous history of DCI, which is not surprising, given the fact that vestibular involvement has been reported to be relatively common in DCI [2,11]. Some residual symptoms are common after vestibular lesions. In the absence of manifest DCI, one might speculate whether repeated minor traumas to the inner ear may accumulate and give rise to permanent symptoms [6,12]. This would be important since vestibular symptoms often have a significant negative impact on quality of life [13,14].

A previous study of working divers did not find evidence of vestibular pathology [15]. However, the study included only 13 divers, who were all free of vestibular symptoms and without a history of significant barotrauma or DCI. In a large cross-sectional study of offshore workers, the prevalence of moderate to severe dizziness and the amount of postural sway measured by static posturography was similar in diving and non-diving personnel [16].

In this study, a prospective longitudinal design was chosen in order to look for evidence of vestibular disorders in a cohort of newly trained divers and to relate this to diving exposure or injuries.

Methods

The protocol was approved in advance by the Committee for Medical Research Ethics at the Research Council of Norway, responsible for enforcing the Helsinki Declaration on medical research involving humans. Participation in the study was based on written informed consent.

The study was a prospective longitudinal cohort study. The target group was working divers in the beginning of their career. Subjects were recruited from *Statens dykkerskole* (Norwegian State Diving School), which is the main institution responsible for training civilian professional divers and diving personnel in Norway. Eighty-four per cent of divers from four classes attending the basic course volunteered to be included in the study, resulting in a cohort of 67 men aged 28 $\pm$ 5 years (mean $\pm$ SD). The subjects were examined three times: before finishing the course, after 3 and 6 years. Each examination included copying of diving logbooks, filling in a questionnaire and interview and examination by a specialist in otolaryngology. The clinical assessment included a general ear, nose and throat examination, examination of the cranial nerves, limb coordination, gait, balance and tests for nystagmus—spontaneous or provoked by lateral gaze, headshake and the Dix-Hallpike manoeuvre. The Dix-Hallpike manoeuvre was used in order to diagnose benign paroxysmal positional vertigo. It was performed by making the patient lie down quickly from the sitting to supine position with the head turned 45 degrees to the side. The manoeuvre was repeated to both sides. Diving exposure was estimated by comparing three different sources of information: the divers' logbooks, the questionnaires and information given by the diver during the doctor's interview. At follow-up, most divers had worked inshore in construction, maintenance and salvage at depths ranging from 0 to 50 m. For that reason, the number of air dives performed during follow-up (6 years) was used as the main exposure variable.

The questionnaire elicited information on vestibular symptoms such as unsteadiness when walking, dizziness and vertigo and their relationships to diving, pressure equalization, ascent or descent. The divers were asked to characterize the dizziness (spinning, rocking and other) when this was relevant. Ear barotraumas and other ear disorders were recorded in the questionnaire. Symptoms experienced after diving, which might represent DCI, were discussed during the doctor's interview.

Postural sway was measured using a static force platform (Cosmogamma®, Italy) measuring 40 $\times$ 40 cm^2 with three strain-gauge pressure transducers. The centre of pressure (COP) under the soles of the feet was sampled by the platform at a rate of 10 Hz. The movements of the COP reflect the corrective forces exerted on the platform by the subject in order to maintain steady posture. Each measurement lasted 180 s. This was repeated with eyes open and closed.

Electronystagmography (ENG) with bithermal caloric testing, registration of positional nystagmus and ocular smooth pursuit was also performed. Spontaneous or positional nystagmus with slow phase velocity $>$5 degrees per second or canal paresis $>$25% was considered abnormal. Canal paresis results from the asymmetric function of the horizontal semicircular canals of the labyrinth, while irregular (saccadic) ocular pursuit may reflect pathology in the cerebellum or brainstem.

Statistical analysis was performed using SPSS® version 15.0 for Windows®. McNemar's test was used in order to test whether the prevalence of symptoms or ENG abnormalities changed during follow-up. The scalar variables age, exposure and postural sway were not normally distributed, and non-parametric tests were therefore used. The Kendall tau test was used to evaluate correlation between exposure and postural sway. The Wilcoxon signed rank test was used to evaluate changes in postural sway during follow-up. The Mann–Whitney test was used in order to test whether the changes in postural sway differed between diver groups. For this purpose, the exposure variable was dichotomized using the median as split point. Analysis in 2 $\times$ 2 contingency tables with Pearson chi-square statistics was used to check for attrition bias.

Results

Complete data (questionnaire, exposure, interview, clinical examination, ENG and posturography) were

available for 51 divers. These divers had performed a total of 27 232 dives during the follow-up period (median: 320; range 2–2000 dives).

Symptoms experienced while diving are shown in Table 1. Of 48 divers who answered the relevant question, 30 reported dizziness or vertigo while diving (63%), most frequently during descent or ascent. Dizziness or vertigo related to pressure equalization during ascent (probable alternobaric vertigo) was reported by 17 divers (35%). Dizziness during descent had occurred in 14 divers (29%). Dizziness related to nitrogen narcosis or temperature changes (possible caloric vertigo) was reported by 13 and 10%, respectively.

Transient dizziness or vertigo 'after' diving was reported by eight (15%) of 53 divers. The character of this vertigo was described as rocking ($n = 6$), spinning ($n = 3$) or both ($n = 2$).

Middle ear barotrauma was reported by 17 of 47 divers (36%). During the interview, two divers reported symptoms that, in retrospect, may have represented DCI. None of these cases had been treated. One diver reported skin symptoms only and another reported transient neurological symptoms (visual disturbances and fatigue).

The prevalence of self-reported long-term symptoms, including unsteady gait, dizziness and susceptibility to motion sickness, did not change significantly during the study period.

There was no significant change in the prevalence of ENG abnormalities (nystagmus, canal paresis and abnormal pursuit) during follow-up.

Postural sway with eyes closed is shown in Figure 1 related to exposure. There was no dose–response relationship between exposure and postural sway with eyes closed at follow-up [Kendall's tau: non-significant (NS)]. Postural sway increased during follow-up but only when measured with eyes closed ($P < 0.01$) not with eyes open. Figure 1 shows that the change in postural sway was not related to exposure (Kendall's tau: NS). The change in postural sway was neither related to the presence or absence of symptoms experienced on land mentioned above, such as occasional dizziness, unsteadiness and motion sickness, nor to having experienced previous barotrauma or vertigo/dizziness episodes during or after a dive.

The clinical examinations did not reveal any cases of vestibular disorders at follow-up.

The divers lost to follow-up did not differ significantly (chi-square test) from the others with respect to problems at diving school such as susceptibility to motion sickness, ear barotrauma or dizziness while diving.

Table 1. Lifetime prevalence of symptoms experienced in 48 divers after diving professionally for 6 years

	n (%)
Have you experienced dizziness or vertigo while diving?[a]	
No	18 (38)
Yes, during ascent	20 (42)
Yes, during descent	14 (29)
Yes, at stable depth	3 (6)
What do you think the cause was?[a]	
Pressure changes	17 (35)
Temperature changes	5 (10)
Other (divers that wrote 'nitrogen narcosis')	6 (13)
Vertigo character[a]	
Spinning	16 (33)
Rocking	6 (13)

[a]The divers were allowed to select more than one alternative.

Discussion

The main finding of this study was that in the absence of inner ear barotraumas and inner ear DCI, there was no evidence of long-term vestibular effects of diving. In contrast to this, the divers had a high lifetime prevalence of transient vestibular symptoms during and shortly after diving, as well as middle ear barotraumas.

The main strengths of the study are the prospective design and the fact that the study group was homogenous with respect to age and training. To our knowledge, there has been no previous prospective longitudinal study on vestibular symptoms or disorders in divers. Optimal data

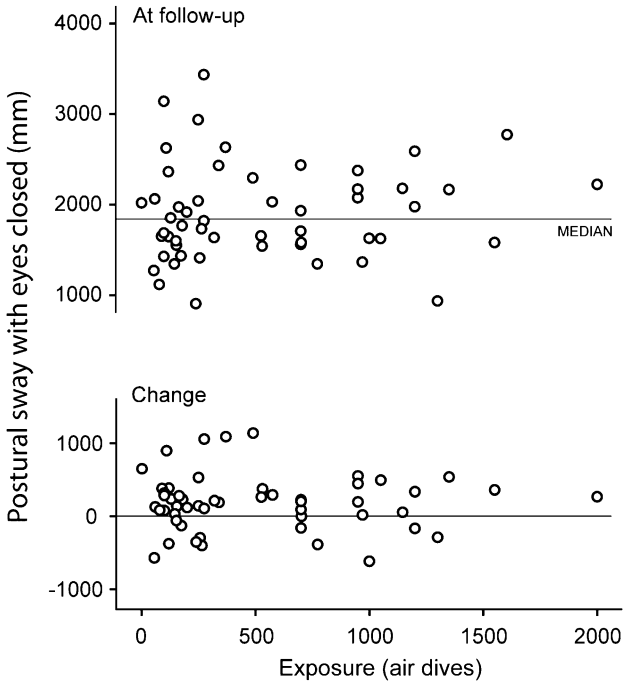

Figure 1. Postural sway related to diving exposure. The upper panel shows that there was no correlation between postural sway at follow-up and exposure (Kendall's tau: NS). The lower panel shows that the mean change in postural sway during the 6-year follow-up was greater than zero (mean = 238 mm, $P < 0.01$) but that this change was not correlated with exposure (Kendall's tau: NS). Postural sway is the length in millimetres of the path described by the centre of pressure under the feet while standing still on a static force platform for 180 s.

collection was attempted by comparing logbooks and questionnaires with information gathered during interviews. The divers were instructed in advance to report all diving incidents and health symptoms. They were young, newly trained and appeared generally motivated for the study. Findings were interpreted after 3 and 6 years by two otolaryngologists with experience in both diving medicine and neurotology.

The diving exposure ranged from 2 to 2000 dives during follow-up, which allows for a reasonable evaluation of a potential dose–response relationship—and a causal link—between diving and postural sway. Previous studies have mostly been retrospective, comparing divers to non-divers, with the limitations recognized for case–control studies.

The study was not designed to address differences between divers and non-divers but to examine changes longitudinally before and after diving exposure and to relate this to the number of dives performed during follow-up. For this reason, it is not possible to conclude with certainty whether the observed increase in postural sway was different from the expected age-related increase reported in previous studies [17]. However, vestibular symptoms and ENG findings were equally prevalent before the divers embarked on their professional career and at follow-up. In the case of postural sway, there was no difference between diving very actively (up to 2000 dives in 6 years) or rarely (down to 2 dives in 6 years). This indicates that a high diving frequency is not responsible for vestibular problems in divers. Consequently, the prevention of vestibular disorders cannot be achieved simply by diving less.

The initial response rate was high (84%), which indicates that the subjects may be considered representative of Norwegian working divers at the beginning of their career. Complete follow-up data were available for most of them (76%). Attrition bias is a potential problem in all longitudinal studies because subjects may drop out for health reasons. However, all non-responders were contacted by phone and encouraged to attend if they experienced any health problems that could be related to diving. Most of the non-responders felt that the examination was irrelevant to them because they were no longer diving and did not have any diving-related health problems. There was no significant association between loss to follow-up and problems at diving school such as susceptibility to motion sickness, ear barotraumas or dizziness while diving. It is therefore unlikely that attrition had a significant impact on the results of the study.

The study used diving frequency as the main exposure variable because one of the objectives was to find out whether frequent diving resulted in more vestibular problems. However, no such relationship was found. We suggest that vestibular disorders are not related to the amount of diving but to events linked to a single dive, such as DCI or barotrauma. The risk of such injuries is related to several other factors, such as diving depth, water temperature, physical exertion as well as the diver's training, experience and supervision. In this study, divers rarely went deeper than 50 m. A previous study of a similar group of divers [18] found that 60% of all dives were performed at depths <10 m. Shallow diving could explain the relatively low incidence of clinical DCI.

Transient vestibular symptoms were experienced by a majority of the divers at some time while diving. The most common cause was alternobaric vertigo. This finding is in agreement with previous studies by Molvær *et al.* [8] and Klingmann *et al.* [7]. Strong vertigo may lead to panic and irrational behaviour, which may be dangerous while under water. The diver may run out of air if forced to delay ascent in order to eliminate vertigo. Vomiting underwater may cause suffocation if wearing a helmet with an oronasal inner mask. In spite of this, no dangerous situations caused by alternobaric vertigo were reported by the divers in this study. This is in agreement with a previous study by Klingmann *et al.* [7].

Transient vestibular symptoms were also relatively common shortly after diving. This is a new finding. Such symptoms may be caused by DCI and should lead to immediate contact with a diving physician. The reason why the divers failed to do so could be that they interpreted their own symptoms as mild or insignificant. After neurotological evaluation, none of the cases were diagnosed as inner ear DCI or inner ear barotrauma.

Long-term vestibular symptoms have been demonstrated in retired offshore divers [10]. In contrast to this, no evidence of long-term vestibular effects was found in this study. Further follow-up of the younger divers is desirable. The offshore divers were more experienced in terms of number of dives and diving years. However, the differences between the groups are not merely quantitative. The offshore divers had a 61% prevalence of DCI. Vestibular symptoms were correlated both with DCI and diving exposure. Among the younger divers, there were no treated cases of DCI (although two possible cases were diagnosed retrospectively). This indicates that the diving practised by the offshore divers was qualitatively different. Deep bounce dives in particular could lead to a higher risk of both DCI and vestibular symptoms.

Acute inner ear DCI and inner ear barotrauma are the only long-term vestibular disorders known to be caused by diving. In this study, the incidence of DCI seems low when compared to the figures reported in a review by Klingmann *et al.* [19], who in their own material found a lifetime incidence of 1:5463 dives in a group of experienced recreational divers. The fact that no cases of inner ear DCI were encountered in this study does not mean that the risk of such injuries should be ignored. Recent reports have indicated that they may be more common than previously thought [1]. However, the lack of cases in our study could be due to the divers' training and awareness of being part of a prospective health study. Klingmann *et al.* [19] found that the lifetime incidence

of DCI increased with decreasing diving experience. Possibly, a certain diving frequency is required in order to achieve and retain the skills necessary to avoid acute injuries. This would agree with our finding that frequent diving was unrelated to postural instability. Adequate training, adherence to existing routines and, possibly, prospective health monitoring may be factors that prevent injuries in working divers.

We have only found one previous study on the prevalence of ENG abnormalities in a group of working divers. Our results agree with those by Sharoni *et al.* [15] who found no evidence of vestibular pathology in their study of 13 asymptomatic professional divers compared to 12 non-diver controls.

Our findings apply to disorders of the vestibular system. Other organ systems have been examined extensively in divers. A recent study found that military divers, even without a history of DCI, had more white-matter lesions on brain magnetic resonance imaging than non-diving controls [20]. The same article also reviewed the evidence from previous conflicting studies. Without a dose–response relationship, it is difficult to determine whether injuries are due to the diving or to other factors that separate divers from non-divers. Such a relationship has been found between diving exposure and hyperoxic lung damage [18], but the inner ear appears to be less sensitive than the lung to hyperoxia [21].

In conclusion, transient dizziness and vertigo is common during and shortly after diving. Although these symptoms appear to be mostly benign, they may be difficult to distinguish from inner ear barotrauma and DCI. Diving carries a definite risk of acute injuries, and a high degree of vigilance is necessary to prevent these from happening. However, there was no indication in this study that frequent diving *per se*, in the absence of acute injuries, leads to permanent vestibular dysfunction.

Key points

- Transient vestibular symptoms and middle ear barotraumas are common in diving.
- This study found no evidence of long-term vestibular effects in a cohort of divers followed over 6 years.
- There was no correlation between diving frequency and postural sway at follow-up.

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Conflicts of interest

None declared.

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