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Co-ordinated investigation into the possible long term health effects of diving at work

Examination of the long term health impact of diving: The ELTHI diving study

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Co-ordinated investigation into the possible long term health effects of diving at work

Examination of the long term health impact of diving: The ELTHI diving study

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We explored self-reported health and health related quality of life in a large group of divers (n=1540 56% response) compared to a non-diving group of offshore industrial workers (n=1035 51% response) with a questionnaire survey. We then validated the questionnaire responses by a detailed clinic assessment of a 10% random sample from each group. This included a range of objective tests and measurements. Finally, we studied reported 'forgetfulness or loss of concentration' in a case-control study, to determine the significance of this symptom and its relationship with diving practice. Health related quality of life (HRQOL) was similar in each group and within normative values. The major work related factor affecting HRQOL was industrial accident and this effect was most marked for offshore workers. A significant group of divers (18%) complained of 'forgetfulness or loss of concentration' and this was related to their diving experience. This complaint was associated with a significant moderate reduction in group mean HRQOL. A random sample of this group had a lower group mean performance on objective tests of cognitive function most particularly of memory and structural differences from control on cerebral MRI were associated with this group. The practice of welding had an unexpected amplifying effect in terms of the symptoms experienced by divers. There was a very high prevalence (50%) of objectively determined hearing disorder in both divers and offshore workers.

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EXECUTIVE SUMMARY

Diving and hyperbaric exposure is associated with a number of well recognised acute illnesses or injuries, including decompression illness (DCI), gas embolism and barotrauma. Recovery depends on the severity and nature of the diving incident, but in many cases it is complete. What remains less certain, however, are the possible long term health effects of diving, particularly in the absence of an injury. Dysbaric osteonecrosis has been associated with diving and is now a notifiable industrial disease in divers. Other aspects of health, however, have raised concern in divers but have not been conclusively associated with a career in diving, with any impact on quality of life or with a disease state. These include neurological abnormalities, lung function changes and inner ear damage.

The aim of the ELTHI diving study (Examination of Long Term Health Impact of diving) was to investigate the possible long term health effects of diving at work. Furthermore, the significance of health complaints was assessed in terms of health related quality of life, as well as by reference to population norms.

Methods

Divers selected for this study had gained a professional diving certificate before 1991, issued by HSE. The comparison group consisted of age matched Oil and Gas industry offshore workers, who had undergone a medical to work offshore between 1990 and 1992, and had never dived. Neither divers nor offshore workers were required to be working as a diver or offshore, respectively, at the time of the study, but they were required to have been working in their respective industry at least 10 years prior to the study. This minimum time period was set to allow symptoms or medical conditions related to their career to become apparent.

The study consisted of two parts, a postal questionnaire survey followed up with a detailed physiological and neuropsychological investigation (clinic study) of a sub-sample of the population who responded to the postal questionnaire survey.

Part 1 –Questionnaire Survey (phase 1a): The questionnaire was sent by post to 2958 divers and 2708 offshore workers. Non-responders were sent the questionnaire a maximum of three times. The questionnaire was designed to assess occupational history, general health complaints, diagnosed medical conditions and health related quality of life (HRQOL).

Part 2 – Clinic study:
10% random sample (phase 1b): this phase of the study consisted a 10% age stratified random sample of divers (n=151) and offshore workers (n=103) who had completed the questionnaire survey. The purpose of this phase was to check the reliability of the postal questionnaire and to identify asymptomatic hearing or neuropsychological deficits that would not have been detected in the postal questionnaire.
Case-control study (phase 2): the largest effect observed between divers and offshore workers was for the complaint of ‘forgetfulness or loss of concentration’, with three times more divers than offshore workers reporting this complaint. Cases therefore comprised ‘forgetful’ divers (F divers) (n=102) while controls were ‘non-forgetful’ divers (NF divers) (n=100) and ‘non-forgetful’ offshore workers (NF OSW) (n=100). Subjects in either section of the clinic study completed the following tests: subjective and objective measures of neuropsychological function, lung function, hearing, balance, a medical examination and detailed occupational history (including diving experience and accidents). In addition to these tests, subjects in the case-control study had MRI of the brain.

Results

Postal Questionnaire survey

The questionnaire survey had a response rate of 56% in divers and 51% in offshore workers. From the returned questionnaires 1540 divers and 1035 offshore workers met the inclusion criteria for the study. Divers were less likely than offshore workers to binge drink frequently, to be current smokers and to have gained higher educational qualifications. Divers were, however, more likely to have had a 3-day lost time accident at work, suffered a head injury and have worked as a welder.

Adjusting analysis for lifestyle factors related to health, divers were more likely than offshore workers to report symptoms of ‘forgetfulness or loss of concentration’, ‘joint pain or muscle stiffness’ and ‘impaired hearing’. Divers were less likely than offshore workers to report skin complaints (itch or rash). Complaints of ‘forgetfulness or loss of concentration’ and ‘joint pain or muscle stiffness’ were associated with a significantly lower HRQOL scores. The reduction in HRQOL for those complaining of impaired hearing was less marked. The greatest difference between the groups was observed for ‘forgetfulness or loss of concentration’, which was three times more common in divers (18%) than offshore workers (6%). Work related accidents and work as a welder were found to be associated with health complaints occurring more commonly in divers. Adjusting for these factors removed differences between the groups for complaints of ‘joint pain and muscle stiffness’ and ‘impaired hearing’ but did not do so for ‘forgetfulness or loss of concentration’. In divers, after accidents and welding were allowed for, ‘joint pain and muscle stiffness’ was related to the amount of surface demand diving, the amount of mixed gas bounce diving and whether the diver had suffered decompression illness. In divers, again after allowing for welding and accidents, ‘hearing impairment’ was related to the amount of saturation diving.

Divers reporting ‘forgetfulness or loss of concentration’ tended to have had longer diving careers and had done more mixed gas bounce, saturation and surface decompression diving. They were more likely to have suffered DCI and adjusting for this factor reduced the relationship between ‘forgetfulness or loss of concentration’ and surface decompression diving, but not its relationship with mixed gas bounce and saturation diving. This suggests that a complaint of ‘forgetfulness or loss of concentration’ was explained by DCI in surface decompression diving but not for mixed gas diving.

There were few differences found between the two populations in diagnosed medical conditions. Offshore workers were more likely to have high blood pressure, asthma and to have had a stroke. Despite divers reporting more factors that were associated with lower HRQOL (symptoms, accidents, head injuries), as a group their reported HRQOL did not significantly differ from that of offshore workers. Further investigation of this paradox demonstrated that the impact of these factors have less of an influence on the HRQOL of divers than that of offshore workers.

Clinic study

i. 10% random sample of divers and offshore workers

Comparison of data with the postal questionnaire: Consistency of reported symptoms indicated a moderate strength of agreement between enquires. This is no more than to be expected after an approximate time interval of 1 year. Kappa values, based on reports from the questionnaire survey (Part 1) and the clinic study (Part 2), for the three main symptomatic differences identified ranged from 0.36 (‘joint pain or muscle stiffness’) through 0.44 (‘forgetfulness or loss of concentration’) and 0.59 (‘impaired hearing’). Subjects complaining of ‘forgetfulness or loss of concentration’ in the questionnaire, as a group, performed less well on objective tests of memory and concentration. Subjects complaining of ‘hearing impairment’ were more likely to have a detectable abnormality in the audiograms than subjects not reporting this complaint. The diving history reported in the questionnaire survey was consistent with the data recalled in the occupational interview. A comparison of accuracy of reported diving experience in the interview was carried out for the 27% of divers who provided full logbooks. Correlation between the number of dives reported and those recorded in logbooks varied for different diving techniques (SCUBA dives: r = 0.52; surface demand dives: r = 0.78; mixed gas bounce dives: r = 0.76; saturation dives r = 0.95).

Abnormalities among non-complainers: Abnormality (below 1.65 standard deviation for the general population) for neuropsychological tests was selected for an incidence rate of 5% in the general population. The incidence of abnormality in non-complainers remained below this rate in all the tests, suggesting that there was no evidence of neuropsychological abnormality that the questionnaire failed to identify. In the hearing test, however, abnormal audiograms were identified for 42% divers and 45% offshore workers who reported that they did not suffer from hearing impairment. This finding was anticipated and is well recognised, because early signs of noise induced hearing loss identified on audiograms are asymptomatic.

ii. Case-control study (‘forgetfulness or loss of concentration’)

There was no difference between the case and control groups in age, alcohol consumption, smoking habits, premorbid IQ or scores of depression or anxiety. F (forgetful) divers scored higher than both control groups on subjective reporting of memory problems and cognitive failure, assessed by standard questionnaires (CFQ and PRMQ). F divers, as a group, performed less well on objective memory and attention tests than the groups of both NF (non forgetful) divers or NF OSW (non forgetful offshore workers). The incidence of frank abnormality (>1.65 standard deviation from population mean), however, for the case and control groups on objective neuropsychological tests suggests that this decline in the F divers is not to an abnormal level. F divers scored higher on subjective reporting of executive dysfunction (DEX) than both control groups. There was no difference, however, between case and controls in performance on objective problem solving (executive function) tests.

The majority (>80%) of case and control groups were found to have white matter abnormalities in the brain. Reported ‘forgetfulness or loss of concentration’ was associated with increased likelihood of periventricular hyperintensities (odds ratio (95% CI) = 2.17 (1.07-4.43)). Eighty two percent of F divers compared to 69% of NF divers had periventricular hyperintensities. Divers had a 1.92-fold increased likelihood of having subcortical or deep white matter hyperintensities compared to offshore workers, but this was not related to forgetfulness. The white matter abnormalities detected in the study population were mild and not unexpected for the age range. Voxel Based Morphometry (VBM), used to characterise regional cerebral volume and tissue concentration differences in MRI showed significant regional grey matter reductions in F divers compared to NF OSW, and also in F divers compared to NF divers. There was, however, no difference between NF divers and NF OSW.

As a group F divers had large and significant differences (>7 points) on all physical and mental HRQOL dimensions of the SF-36 compared to NF divers and NF OSW.

F divers had done a significantly greater number of dives than NF divers during their career. Furthermore, F divers were more likely to have done mixed gas bounce, saturation and surface decompression diving. F divers were more likely to have suffered neurological and pain only DCI, but adjusting for this in the analysis did not alter the difference in the objective neuropsychological test results.

Summary

The questionnaire survey identified three complaints that were more common in divers than offshore workers; 'forgetfulness or loss of concentration', 'joint pain or muscle stiffness' and 'impaired hearing'. Difference in complaints of 'joint pain or muscle stiffness' and 'impaired hearing' were associated with work related factors found to be more common among divers (e.g. welding and lost time accidents). Divers were three times more likely to report symptoms of 'forgetfulness or loss of concentration' than an age matched group of offshore workers. The complaint of 'forgetfulness and loss of concentration' was found to be the most significant long term health effect and was not explained by factors such as welding, 3-day accidents, head injury, DCI and lifestyle (age, alcohol consumption, smoking). Divers with longer diving careers were more likely to report that they suffered 'forgetfulness or loss of concentration'. Dose-response effects for this subjective complaint were found for specific diving techniques; mixed gas bounce, surface oxygen decompression and saturation diving. However, among divers in the case-control study, there was no substantive relationship between objective cognitive performance and the amount of diving performed.

In the case-control study, in which F divers were compared with control groups of NF divers and NF offshore workers, F divers were found to perform more poorly on objective neuropsychological tests of memory and concentration. Diving experience continued to be significantly associated with 'caseness', with F divers having done significantly more dives than NF divers. Consistent with the questionnaire survey a higher proportion of F divers had done mixed gas bounce, surface oxygen decompression and saturation diving than NF divers.

Taking into account confounding factors, 'forgetfulness or loss of concentration' was found to be associated with an increased incidence of periventricular hyperintensities on MRI. Periventricular hyperintensities have been related in previous studies to lower cognitive performance. Divers were found to have an increased likelihood of subcortical or deep white matter hyperintensities compared to offshore workers, but this was not related to forgetfulness.

An interesting finding of the study was that divers, as a group, did not rate their HRQOL differently, despite a greater proportion of divers having symptoms that are usually associated with lower HRQOL. It appeared that symptoms such as joint pain, hearing loss and forgetfulness had less of an impact on divers than offshore workers. The case-control study found significant deficits in HRQOL of F divers, compared to NF divers and NF offshore workers. This suggests that the HRQOL impact of forgetfulness could have been disguised in the screening survey, when only the minority of the population are reporting the complaint of 'forgetfulness or loss of concentration'.

In summary, the ELTHI diving study did not identify any long term health effects associated with professional diving amounting to a clinical abnormality, although 'forgetfulness or loss of concentration' complaint was associated with significant impairment of HRQOL and MRI changes. The extent of the neuropsychological effect observed in forgetful divers was at a level indicative of mild sub-clinical deficit. The concerns now must be to distinguish whether this represents one point on a progressive decline of function or merely the result of some form of diving related insult with stable consequences and to establish whether any form of recovery occurs after cessation of diving.

CONTENTS

1 INTRODUCTION

Diving and hyperbaric exposure is associated with a number of well recognised acute illnesses or injuries, including decompression illness, gas embolism and barotrauma. Depending on the nature and severity of the accident a diver may make a full recovery but also may sustain a long term reduction in health. Diving is also associated with dysbaric osteonecrosis, a recognised industrial disease in divers and caisson workers. In spite of some indicative research, in the absence of either an acute hyperbaric illness or osteonecrosis, there remains uncertainty regarding the potential for a diving career to cause long term health effects.

Concern about long term health effects has arisen from several sources, which include anecdotal case reports of illness in divers and investigations of subclinical abnormality within the hyperbaric workforce. Neurological abnormality, lung function abnormality, inner ear injury and bone disease have been the principal areas of concern, although other areas include the locomotor system, skin and liver function particularly in saturation divers. Previous studies investigating the health effects of diving are summarised below:

Dysbaric osteonecrosis: This is the best recognised long term health effect of diving. Surveys show a variable incidence of dysbaric osteonecrosis in different diving and caisson worker populations (1). Although there does appear to be a threshold in terms of an inert gas load required to induce this disorder, the precise factors (e.g. depth, duration of exposure, nature of inert gas and profile of decompression) remains unclear.

Neurological effects: Studies of the effects of hyperbaric exposure on the nervous system fall into four main areas:

1. Clinical and neurophysiological status: Long term neurological deficit occurring after clinical episodes of decompression illness (DCI) was recognised by Rozsahegyi *et al.* in 1966 (2) who described various patterns of permanent neurological injury. He also reported neurological abnormality in workers who had not reported clinical episodes of acute DCI (2).

Neurological studies performed by Todnem *et al*. (3-5;6) investigated the acute effects of hyperbaric exposure during deep experimental diving on nervous system function. These dives were concerned with investigation of High Pressure Neurological Syndrome (HPNS) and methods of control, demonstrating that there were acute disturbances of both central and peripheral nervous function during deep dives. These divers were followed up for a period of up to 7 years and were found to have more neurological symptoms and abnormalities on clinical examination (4) than a control group of non-divers. These findings correlated best with previous episodes of DCI. In all of these studies, however, there was a high incidence of previous decompression illness in the divers studied and therefore the impact of diving in the absence of this disease was not convincingly demonstrated. Since divers may return to work after an episode of DCI if deemed to have recovered by the examining doctor, it is likely that the neurologist involved in the study would pick up various abnormalities which were either missed by the examining doctor or which developed at a later date. More recently a study sponsored by HSE (7) to investigate neurological abnormality in commercial divers using spinal evoked potentials found only a minor impairment in latency in divers compared to controls. Hence, while there is a strong suggestion that the population of working divers have more neurological abnormality than a control population, this does not appear to correlate well with abnormality on examination or the results of electrophysiological investigation and it remains possible that the abnormalities detected represent late effects of acute episodes of DCI.

2. Neuropsychological function: Neuropsychological investigations have been pursued by the Norwegian investigators (8-11) who initially investigated the acute effects of deep experimental dives on psychological function. Significant abnormality was associated with the development of HPNS. In working divers they found minor abnormalities, not associated with symptoms but possibly related to saturation diving exposure. Divers have been found to perform less well than controls in tests of memory (7;12-14) to report a higher rate of subjective cognitive failure (13) and to have poorer psychomotor performance (7). On the other hand, other neuropsychological studies carried out in US Navy divers (15) and Australian divers (16) have failed to demonstrate any definite neuropsychological abnormality in divers who had not experienced an acute episode of decompression illness.

3. Imaging studies: Imaging of the nervous system has been investigated using various techniques. It is generally agreed that X-ray including CT examination of the brain does not readily detect the lesions associated with DCI, let alone more minor abnormality. A variety of studies have been performed based on the use of hexamethy propylene amine oxime single photon emission computed tomography (HMPAO SPECT). While this technique was initially felt to be a valuable indicator of cerebral abnormality (17) it has since become clear that the technique reveals a high rate of "abnormality" in control subjects and the location of the lesions identified do not correlate well with clinical signs (18). Its place in the detection of subtle long term effects therefore remains unclear. More recently HMPAO- SPECT studies using texture analysis have suggested a relationship to diving activity, there being a difference in mean grey level between non-divers, divers with and divers without a history of DCI (19;20). Similar findings have been reported in the sport diving community (21). The overlap between groups was substantial and at present the limited specificity of the technique, together with the ethical problems associated with the radiation dose required, make it difficult to justify in further epidemiological study.

Magnetic resonance imaging (MRI) has been more widely used. MRI is a sensitive method for detecting minimal brain morphological changes. Brain white matter abnormalities are usually separated into two broad categories: periventricular hyperintensities (PVH) and subcortical and deep white matter hyperintensities (WMH). Again, considerable enthusiasm greeted its application to diving related neurological injury. The specificity, however, of the technique remains in doubt because of the high incidence of these appearances in normal control subjects. Nevertheless, several studies have shown an increased incidence of white matter abnormalities in divers (14;22;23) and a relationship between their presence and the existence of a patent foramen ovale, a known predisposing factor in DCI (24;25). As with other neuroimaging techniques, there are several studies in which these effects were not seen (26-29) and no consistent picture emerges. The more direct imaging technique of retinal angiography has identified a reduction in capillary density in the retinae of divers which is related to the length of diving career and with a greater reduction in those that had experienced decompression illness (30). There were no symptoms or visual disturbance associated with this observation and a subsequent study on a smaller group of naval personnel failed to find any differences in divers (31).

4. Histological examination of post mortem material: Histological studies on spinal cord from post mortem examinations has demonstrated substantial abnormality in a diver who had made a reasonable clinical recovery from decompression illness. The extent of the histological damage raised concern about permanent injury in any diver who had sustained an acute episode of neurological decompression illness (32). Further studies of material from divers without a previous history of DCI supported this concern (33) although the analytical techniques used were unusual and not in common neuropathological practice. Studies on brain material have been less convincing with dispute over the significance of the possible lesions identified (33).

Finally, work by a different research team failed to find any evidence of spinal cord damage or change in post mortem tissue from a group of 20 divers (34).

In summary, neurological abnormalities are well recognised in divers who have sustained acute DCI. In divers who have not sustained an acute episode of DCI there is evidence suggestive of subtle neurological impairment. None of the studies associated these differences seen in divers with a disease state or any effect on health related quality of life.

Lung function: There is little doubt that diving affects lung function and numerous studies of the diving population have demonstrated that they tend to have large lungs, probably as a result of respiratory muscle training associated with the use of breathing apparatus, immersion, and increased breathing gas density (35-39). These studies have demonstrated a greater increase in the Forced Vital Capacity (FVC) than in the Forced Expiratory Volume in 1 second (FEV1) leading to a reduced ratio, which in other circumstances might be indicative of airflow obstruction. More detail evaluation of divers demonstrates flow volume loop appearances consistent with a degree of small airway obstruction (40-42). This has been attributed to both bubble related injury occurring during decompressions and to chronic oxygen toxicity (43-46). Limited longitudinal studies have been carried out, both retrospectively (47) and prospectively on divers involved in deep experimental dives (48;49) and these demonstrate decline in lung function at a rate faster than would be predicted on the basis of ageing alone. Despite physiological abnormalities having been demonstrated, the potential long term effect of this abnormality remains unclear.

Otological function: A number of studies have demonstrated that commercial divers have hearing deficits, including a greater than expected decline in hearing with age (50-52). It is unclear whether the deficit results from hyperbaric exposure or exposure to noise (53), from barotrauma or from non hyperbaric related work.

Skin disease: The prevalence of skin disease in the diving population is high. Although this is generally considered to be a minor problem, chronic fungal infection is common and the phenomenon of divers hand remains unexplained (54). There is increasing concern over the development of skin injury and sensitisation due to the problems of preventing exposure to toxic materials.

Other disorders: Diving physicians have encountered cases of experienced divers developing unexplained joint disease predominantly affecting the upper limb girdle in the absence of evidence of dysbaric osteonecrosis, the cause of which is uncertain. There are a number of additional areas where normal physiological function is deranged during diving, e.g. hepatic function, in which the possible long term effects have not been studied.

The overall current situation with regards divers' long term health was summarised in the consensus of the Godoysund Conference (1993) (55 p.391) stating "there is evidence that changes in bone, the central nervous system and the lung can be demonstrated in some divers who have not experienced a diving accident or other established environmental hazard. The changes are in most cases minor and do not seem to influence the diver's quality of life in as far as this has been assessed. However, the changes are of a nature that may influence the diver's future health. The scientific evidence is limited, and research is required to obtain adequate answers to the questions of long term health effects of diving".

2 OBJECTIVES

The aim of the ELTHI diving study (Examination of the Long Term Health Impact of Diving) was to assess the possible long term health effects of professional diving.

Specific objectives included:

a. to describe health complaints or diseases reported by a professional diving population
b. to compare health complaints or diseases reported by professional divers with a comparison group
c. to determine the influence of diving experience on divers' health
d. to determine the impact of professional diving on health related quality of life (HRQOL)

3 METHODOLOGY

3.1 STUDY DESIGN

The ELTHI diving study consisted of two parts (Figure 1). Both parts were submitted to and approved by the Grampian Region Ethics Committee. Part 1 was a postal questionnaire survey designed to determine the general health status and health related quality of life of professional divers (phase 1a). The questionnaire was used also as a screening tool to identify subjects for the case-control study in Part 2. Part 2, the clinic study, involved a series of detailed neuropsychological and physiological examinations of a subgroup of the original population from Part1 (phases 1b and 2) with MRI brain scanning.

There were two objectives of phase 1b. Firstly, 10% of the original population from Part 1 was randomly selected to test the reliability of the postal questionnaire. Secondly, the same random sample was used to compare a series of objective assessments between divers and offshore workers.

Case-control study were to be designed for phase 2, based on health complaints reported in the questionnaire survey showing the greatest difference between divers and offshore workers. In the final analysis, only one such study was justified. The most significant difference was for the complaint of ‘forgetfulness or loss of concentration’, which was three times higher among divers (18%) than among offshore workers (6%). This complaint was therefore used as the basis of a single case-control study.

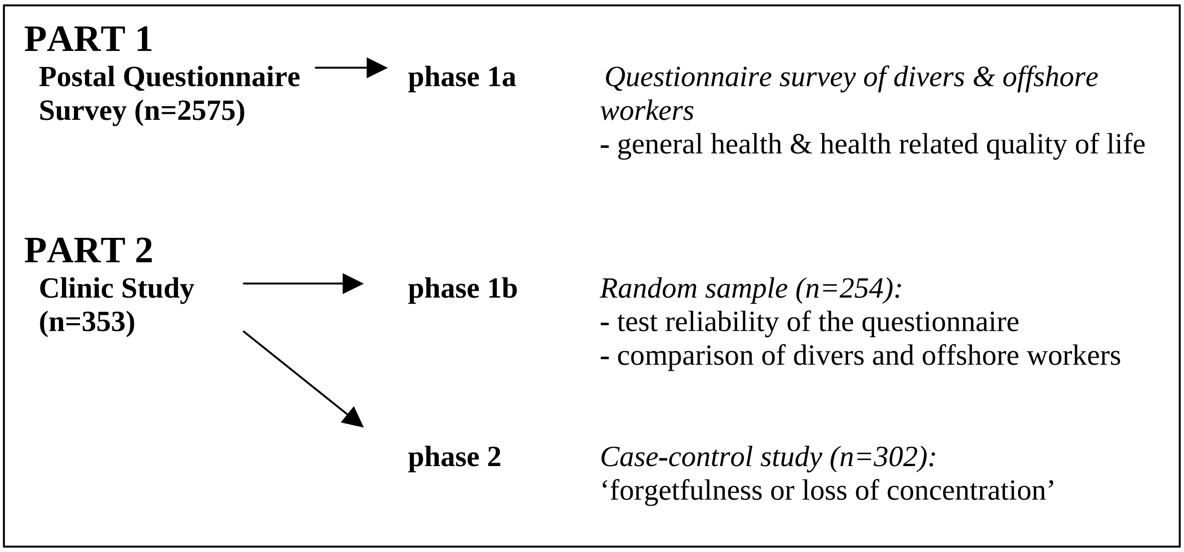


Figure 1 Study design for the ELTHI diving study

3.2 PART 1 - QUESTIONNAIRE SURVEY

The questionnaire was divided into four sections, assessing (Appendix 1):

1. ***Demographic and lifestyle characteristics***: smoking, alcohol consumption, educational attainment, marital status, employment status, date of birth.

2. ***Occupational history:*** professional and recreational diving exposure, offshore work, welding, 3-day lost time accidents, diving accidents, exposures to substances and noise at work.
3. ***General health***: current medical symptoms/health complaints and diagnosed medical conditions.
4. ***Health related quality of life (HRQOL):*** SF-12 (56).

Alcohol consumption was reported in terms of frequency of 'binge drinking', defined as the consumption of 8 or more units on any single occasion. Offshore workers were asked if they had ever done any recreational diving, since this identified those to be excluded from the comparison group. A 3-day lost time accident at work was defined as the industry standard of an accident or injury that resulted in more than 3-days off work. Symptoms, listed on the questionnaire, were rated on a four-point scale based on degree of suffering (not at all, slightly, moderately, extremely).

The list of symptoms included 'joint pain or muscle stiffness', 'back pain or neck pain', 'breathlessness', 'cough or wheeze', 'abdominal pain, diarrhoea, constipation or nausea', 'muscle weakness or tremor', 'unsteadiness when walking, dizziness or poor balance', 'forgetfulness or loss of concentration', 'impaired vision (not corrected by spectacles)', 'impaired hearing' and 'skin rash or itch'.

The SF-12 questionnaire is expressed as two summary scales: Physical Component Summary (PCS) and Mental Health Component Summary score (MCS). The PCS and MCS scores are transformed to norm based scores, giving standardised scales with a mean (SD) of 50 (10) in the UK population. Higher scores indicate better quality of life. One way of expressing the magnitude of difference is to use effect size. Effect size expresses the mean difference between two groups as a fraction of the pooled standard deviation. An effect size (d) of 0.2 to 0.4 is regarded as small to moderate and therefore a minimum clinically significant effect in health outcome measurement (57). An effect size of 0.8 is regarded as large.

Social deprivation was derived from postcodes, using the Carstairs deprivation index, based on the small area census data (58). The index is a standardised score with zero as the national mean score and a standard deviation of approximately 3.5. A negative score indicates less deprivation.

The questionnaire was piloted on a small group of local divers and offshore workers. The final version of the questionnaire was then sent to all the traced divers and offshore workers by post with a pre-paid return envelope. Non-responders were sent a maximum of three questionnaires at four weekly intervals.

3.3 PART 2 – CLINIC STUDY

Subjects were sent a letter inviting them to take participate in the clinic study, which required them to spend a full day at the National Hyperbaric Centre (Aberdeen); an example of a typical test day is shown in Appendix 2. Subjects were asked to refrain from drinking alcohol for 24 hours before attending the study.

3.3.1 Assessments

Divers and offshore workers recruited for Part 2 of the study all completed the same series of tests and examinations with the exception of an MRI of the brain. Only those included in the case-control study had MRI. Details of all the tests are described in Appendix 2.

Neuropsychological Assessments: Neuropsychological tests can only measure current levels of cognitive functioning. Thus, in cases where impairment is suspected, comparison is necessary between current level of functioning and premorbid level to indicate extent of deterioration. When no premorbid test results are available an estimate of premorbid IQ can be obtained from the National Adult Reading Test (NART). This test of premorbid IQ produces scores that are largely resistant to central nervous system damage, compared to ‘current IQ’ scores that are sensitive to central nervous system damage. Current IQ can be categories into two areas, crystalline intelligence (refers to accumulated knowledge) and fluid intelligence (refers to the efficiency in solving new problems). Premorbid and current levels of IQ were both assessed. Neuropsychological assessments were selected from a comprehensive test battery of neuropsychological function. Cognitive functions assessed by these tests included visual and verbal memory, psychomotor speed, attention, executive functions (planning, attention set shifting and working memory), and global intellectual function (Table 1). Testing was by accepted questionnaires and face to face interview with the team psychologists. A computerised test battery CANTAB (Cenes, Cambridge) was used for further neuropsychological tests, which was also supervised by psychologists.

Table 1 Summary of the function of the neuropsychological tests

Neuropsychological tests	***Function of test***
Intelligence (IQ)	
NART WAIS-R IQ	Premorbid IQ
WASI full scale IQ	Current IQ
- WASI vocabulary	- crystalline intelligence
- WASI matrix	- fluid intelligence
Subjective questionnaire assessments	
Prospective/Retrospective Memory (PRMQ)	Failure of memory
Cognitive Failures Questionnaire (CFQ)	Failure of memory, perception & action
Dysexecutive Questionnaire (DEX)	Failure of executive functioning
Objective assessments	
Logical Memory (LM)	Verbal memory & learning
CVLT-II	Verbal memory & learning
CANTAB:	
Reaction Time (RTI)	Divided attention and motor speed
Rapid Visual Processing (RVP)	Sustained attention
Spatial Recognition Memory (SRM)	Spatial memory
Intra Dimensional/Extra Dimensional Shift (IDED)	Attention set shifting (executive function)
Stocking of Cambridge (SOC)	Planning (executive function)
Spatial Working Memory (SWM)	Working memory (executive function)

Definition of abnormality: For neuropsychological data, abnormality was defined as a score of 1.65 standard deviations below the normative population mean. This level was chosen because it represents the 5^{th} percentile, such that comparisons could be made for the incidence of abnormality in this sample against that occurring in the general population.

Questionnaires: Subjects completed a number of questionnaires to assess a range of characteristics, including:

- *Background Questionnaire*: age, education, handedness, diagnosis of dyslexia
- *General Lifestyle Questionnaire*: smoking habits and alcohol consumption
- *Hospital Anxiety and Depression Scale (HADS):* measure of depression and anxiety
- *SF-36:* Short form 36 health related quality of life
- *ALAPS*: personality characteristics

Medical Examination: Independent medical doctors were brought into the study to perform the medical examinations. The doctors were blind to the results of Part 1 of the study and whether the subject they were examining was a diver or an offshore worker. The medical consisted of a general prestructured examination, including neurological and locomotor examination, followed by a semi-structured interview for medical history and complaints. Thus, the examination was conducted with the doctor blinded to the medical history. The medical history enquired about current symptoms, all medical conditions and head injuries.

Occupational & Accident History: An occupational and accident history was taken by a specialist in Hyperbaric Medicine. During the interview detailed information on diving experience was collected from the divers. Further to the interview, divers were asked to bring to the study their professional diving log books, covering the duration of their diving career. The number, type and depth of dives were recorded from the log books and used as a comparison with the information recalled in the interview.

Audiometry Test: Subjects first completed a background questionnaire assessing noise exposure, ear complaints and subjective hearing loss. An automatic self-recording audiometer (ASRA 2001 – GM Instruments Ltd), was used to perform threshold hearing tests at frequencies of 1000, 2000, 3000, 4000, 6000, 8000 and 12000 Hz. The test was conducted in a sound proof hearing booth.

Two occupational physicians familiar with audiometric screening in occupational health independently read all the audiograms blind. After reading the audiograms independently, the results were compared and any audiograms where the classification differed were reviewed and the final classification agreed by consensus. Each ear was classified separately.

Definition of abnormality: Any single threshold more than 15 dB greater than normal for the individual's age was classed as abnormal. Within the abnormal category, audiograms were defined as consistent with mild, moderate or severe noise induced hearing loss using the following criteria selected to identify typical patterns of noise induced hearing loss:

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 2 adjacent frequencies of ≥15 dB
Severe	high tone threshold ≥50 dB greater than normal with step reduction between 2 adjacent frequencies of ≥15 dB

Lung Function: A series of lung function tests were performed to obtain the following measurements:

- Peak expiratory flow rate (PEF)
- Forced vital capacity (FVC)
- Forced expiratory flow at 1 second (FEV1)
- Forced expiratory volume/forced vital capacity (FEV1/FVC)
- Forced expiratory flow at 25% and 50% expired FVC (FEF25%, FEF50%)

Diffusing capacity for carbon monoxide DLCO and transfer coefficient KCO (diffusing capacity per unit lung volume) were used as a measure of gas exchange capacity of the lungs. Total lung capacity (TLC), the volume of gas contained in the lung after a full inhalation, and residual volume (RV), the volume of gas remaining in the lung following a maximal expiration, were both measured. Residual volume/total lung capacity ratio (RV/TLC) was used as an indication of airway obstruction.

Stabilometry: Tetra-axial stabilometry was performed (Force platform by Tetrax, Israel) to identify equilibrium disturbances, by measuring the postural sway of divers and offshore workers. Thirty second measurements were made in 8 different positions including, with the eyes open and closed, and with and without soft pads beneath the feet. A higher score indicates poorer postural control.

Magnetic Resonance Imaging: Magnetic resonance imaging (MRI) of the brain was conducted on a 1.5 Tesla system (General Electric, Milwaukee, Wi) using the following sequences: T2 weighted axial, fluid attenuated inversion recovery (FLAIR) axial and T1 weighted 3D volumetric acquisition. FLAIR images show white matter abnormalities as high signal that appear bright, while free water is suppressed. This means that cerebrospinal fluid in the ventricles and sulci appears dark. Subjects were excluded from the scanning procedure if any of the usual contraindications to MRI were present such as a cardiac pacemaker, other implanted metallic device, metallic foreign bodies or significant claustrophobia.

Two experienced, blinded observers scored the FLAIR images using a modified Scheltens scoring system devised for this project (see Appendix 2) (59). This system included scores of subcortical and deep white matter hyperintensities (WMH) and periventricular hyperintensities (PVH). WMH were scored according to size, number and anatomical location (frontal lobe, parietal lobe, temporal lobe, occipital lobe and internal capsule). Periventricular hyperintensities were scored as either present or absent around the frontal horns, bodies or occipital horns of the lateral ventricles. Between and within observer variation of this modified scoring system has previously been assessed by the observers and found to be as good as published studies. When the two observers differed in WMH score by 3 or more points, a consensus score was obtained by reviewing the images. When the score differed by 2 points or less a mean score was derived. FLAIR images were also simultaneously scored using the Fazekas system (60). Score differences in this system were revised by observer consensus.

The T1 weighted volumetric data was analysed based on the ‘Optimised Voxel Based Morphometry (VBM) Protocol’ (61), using Statistical Parametric Mapping 2 (http://www.fil.ion.ucl.ac.uk/spm), with normalisation to the standard T1 template. This is a method of segmenting grey matter, white matter and CSF in standard stereotactic space and allows comparison of volumes of these tissues between subject groups. Regionally specific differences in grey matter between groups were assessed with an analysis of co-variance, with total brain volume as a confounding variable.

3.4 STUDY POPULATION

The study population comprised of professional divers and a comparison group of age matched Oil and Gas offshore workers. There was no requirement for either the divers or offshore workers to be working in their respective industries at the time of the study. Including people who no longer worked in the industry reduced the possible introduction of survivor bias. There was no minimum or maximum restriction on the duration of individuals' diving or offshore career. Only one criterion was set and this required them to have been working in their respective industry a minimum of 10 years prior to the start of this study. This minimum period was set to give time for symptoms or medical conditions relating to their career to manifest.

3.4.1 Divers

Divers were selected from the Health and Safety Executive (HSE) records of professional divers' training certificates and were required to have obtained a diving certificate before 1991. The study was restricted to men, for although there were a small number of women divers, the numbers meeting the study criteria on the HSE records were too small to analysis separately. A further requirement was for divers to have a current UK address.

3.4.2 Comparison group: Oil and Gas offshore workers

The comparison group of age matched group of Oil and Gas offshore workers were identified from offshore medical records of Liberty Occupational Health Ltd (now AON Health Solutions, Aberdeen, UK). The offshore workers were required to have had an offshore medical examination of fitness to work offshore between 1990 and 1992, to hold a current UK address and to have never dived professionally or recreationally.

3.4.3 Identification and tracing of subjects

Prior to the study, the accuracy of all addresses was checked by a data verification company (Data Discoveries Ltd, Edinburgh, UK). Where the name no longer matched the given address several methods were employed to trace a current address. These methods included data from medical records from HSE and AON Health Solutions (formally Liberty Occupational Health Ltd), the Community Health Index (Grampian region only), commercial tracing (Data Discoveries Ltd) and other publicly available information. Current addresses were traced for 2958 divers and 2708 offshore workers.

3.4.4 Sampling of subjects for the clinic study (Part 2)

A total of 353 subjects participated in the follow up clinic study, which had 2 phases. Phase 1b consisted of a 10% (n=254) sample of those who completed Part 1 and was stratified according to age, head injury and complaint of 'forgetfulness or loss of concentration'. The case-control study (phase 2) was based on a sample of 302 subjects, none of whom had previously reported a head injury. Cases (n=102), consisting of divers complaining of moderate or extreme forgetfulness or loss of concentration, were compared with two control groups: 100 non-forgetful divers and 100 non-forgetful offshore workers. It was not possible to make comparisons with forgetful offshore workers as there were insufficient numbers in Part 1 reporting this complaint. Those subjects from phase 1b that met the criteria for phase 2 were included in both phases (Table 2).

Subjects were randomly selected from within the stratified groups until the required number of subjects had completed the study. Subjects having moved abroad (n=12) or offshore workers that had recreationally dived (n=5) since completing the phase 1a were excluded from Part 2.

Table 2 Distribution of the groups the clinic study (phase 1b and phase 2)

	No head injury		*Head injury*		*missing*	
	forgetful	***not forgetful***	***forgetful***	***not forgetful***	***data****	***TOTAL***
	n (n_1)	***n (n_1)***	***n***	***n***	***n***	***n(n_1)***
Divers	20 (102)	100 (100)	6	18	7	**151 (202)**
Offshore workers	5 **	83 (100)	0	8	7	**103 (100)**

n= number of subjects in random sample (phase 1b), n_1= number of subjects in the case-control study (phase 2), *missing data = data was missing on the questionnaire survey for either head injury or forgetfulness, ** there were insufficient numbers for a control group in the case-control study

3.5 STATISTICAL ANALYSIS

3.5.1 Questionnaire survey

Univariate analysis was used as appropriate to compare lifestyle and demographic characteristics of divers with offshore workers. The internal consistency of the questionnaire was assessed comparing the responses to related questions (Chi-Square test).

***Logistic regression*:** Logistic regression models were used first to determine differences between offshore workers and divers, and then to establish the relationship of the differences found with occupational exposure.

In order to determine differences between divers and offshore workers for the reported symptoms, the variables were dichotomised into those who reported suffering 'not at all' or 'slight' and those suffering 'moderate' or 'extreme'. Unadjusted and adjusted logistic regression models were used to identify any statistically significant differences between divers and offshore workers in reported symptoms and diagnosed medical conditions. Models were adjusted for the following covariates: age, smoking habits, frequency of binge drinking alcohol and head injury. Body mass index (BMI) was included in the models predicting 'joint pain or muscle stiffness' and 'back pain or neck pain'. Educational attainment was included in the model predicting 'forgetfulness or loss of concentration'.

In the model relating to occupational exposure, data for each of the diving techniques was converted from a categorical into a continuous variable. This was achieved by taking the mid-value of the range in each category. For the highest category, which had no upper limit (e.g. >1000), the value was estimated from information based on the diving history interview in Part 2 of the study on the 10% random sample of the questionnaire population. The median value was taken for all those divers who fell into the upper category:
SCUBA (n=44): 1688 dives
Surface oxygen decompression (n=8): 1584 dives
Other air/nitrox (n=76): 1020 dives
Saturation (n=24): 1500 days
For mixed gas bounce diving none of the divers in Part 2 had done more than 500 dives (i.e. in the highest category used in the questionnaire), therefore the midpoint (300 dives) of the previous category was used. These 'continuous' variables for SCUBA, surface oxygen decompression, other air/nitrox dives (i.e. surface supply/demand with air or nitrox), mixed gas bounce and saturation dives were included in a single logistic regression model, adjusted for age, smoking, binge drinking, head injury, having worked as a welder, lost time accidents and main group (diver *vs.* offshore worker). In this analysis educational attainment was not included in the model predicting the likelihood of forgetfulness or loss of concentration as there

was an inverse correlation between years in education and diving experience. Divers with higher educational qualifications had done fewer dives than those with lower educational qualifications. From this it was assumed that educational attainment in divers reflected diving career rather than premorbid IQ. In other words divers had gone diving rather than continuing in higher education and educational level therefore did not reflect intelligence in this group. Including educational attainment into the model would have then adjusted for the effect of diving twice.

HRQOL (SF-12) was analysed using analysis of variance (ANOVA) and analysis of covariance (ANCOVA). In the ANCOVA the factors adjusted for included age, smoking, binge drinking and head injury.

***Multiple linear regression*:** Factors predicting HRQOL from the SF-12 were assessed using separate multiple linear regression models for PCS and MCS scores. Factors were added into the model hierarchically, with the main group (divers *vs.* offshore workers), followed by lifestyle and demographic factors and then work related factors. Finally the main symptoms found to differ significantly between divers and offshore workers were included in the model.

Power: It was aimed to achieve replies from 1500 divers and 1000 offshore workers. For Chi Square testing with continuity correction these numbers gave 80% power at the 0.05 probability level to detect differences of 2 to 6% between groups.

3.5.2 Clinic study

Some of the neuropsychological data from CANTAB required transformations before the data were analysed; the 5 choice reaction time (log10), Spatial Recognition Memory (arcsin) and Rapid Visual Processing (arcsin).

Multivariate analysis of variance (MANOVA): Since many of the neuropsychological test variables were highly correlated, MANOVA was the procedure selected for the comparisons between divers and offshore workers. This analysis reports the main effect, controlling for the impact of the other measures entered into the multivariate analysis. Separate MANOVA were conducted for objective and subjective neuropsychological assessments. Models were adjusted for age, premorbid IQ, years of education, anxiety, depression, alcohol consumption (units per year) and pack years (smoking). MANOVA was also conducted for the HRQOL (SF-36), adjusting for age, alcohol consumption (units per year) and smoking (pack years).

3.5.3 Checking the results of the questionnaire survey

Comparisons were then made using several methods to test the questionnaire data against objective measurements made in Part 2. These included tests of sensitivity and specificity, kappa values and correlations.

Reliability tests: The level of sensitivity and specificity was calculated for the information collected in the questionnaire survey against objective tests made in Part 2 of the study, indicating the proportion of people correctly categorised.

> **Sensitivity** is the proportion of symptomatic people in the questionnaire that were confirmed as symptomatic by objective tests
> **Specificity** is the proportion of asymptomatic people who were confirmed as such by the objective tests

Cohen's kappa values were used as a measure of agreement for categorical data where no objective measure was available. The maximum possible kappa value is 1, indicating perfect agreement, and the interpretation of lower values are illustrated in Table 3.

Table 3 Interpretation of kappa values

kappa value	**Strength of agreement**
< 0.20	Poor
0.21 - 0.40	Fair
0.41 - 0.60	Moderate
0.61 - 0.80	Good
0.81 - 1.00	Very good

Correlations were used as a measure of agreement for trend, rather than absolute agreement between categories.

All analysis was conducted using the statistical package SPSS (version 11.0).

4 RESULTS

4.1 PART 1: POSTAL QUESTIONNAIRE SURVEY

4.1.1 Response rate

The overall response rate, with the exclusion criteria, is illustrated in Figure 2. 1525 (56%) divers and 1284 (51%) offshore workers returned a completed questionnaire. Excluding those who failed to meet the criteria for the study left 1540 divers and 1035 offshore workers in the analysis.

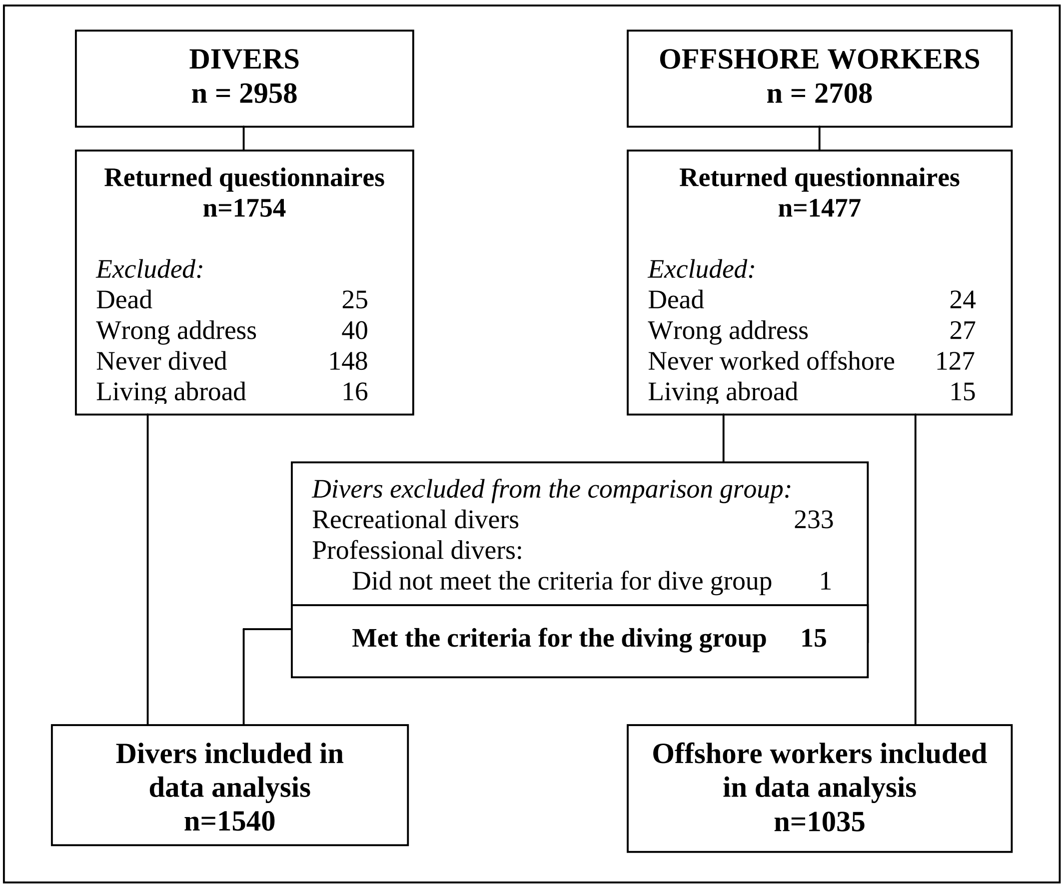


Figure 2 Response rate in the questionnaire survey

Response bias (non-responders): Insight into the possible characteristics of non-responders was gained by comparing participants who returned the first questionnaire with late responders who sent back the third questionnaire. This methodology has been used previously to identify possible characteristics of non-responders (62). The first mailing produced a response rate of 66% in divers and 63% in offshore workers, reducing to 24% in both groups in the second mailing, and 10% and 13%, respectively, in the third mailing.

Late responders did not differ from early responders in diagnosed medical conditions, HRQOL or symptoms, other than back or neck pain which was less common among late responders (p=0.04). They did not differ in age, social deprivation or binge drinking but late responders, however, were more likely to be a current smoker (p=0.005) and have lower educational qualifications (p=0.02).

4.1.2 Demographic and lifestyle characteristics

Table 4 summarises the general characteristics of divers and offshore workers. Divers were less likely than offshore workers to binge drink alcohol, be a current smoker or to have gained higher educational qualifications. Divers and offshore workers did not differ significantly in marital status, living situation or level of social deprivation (measured by Carstairs). The negative Carstairs scores found for both divers and offshore workers indicates higher affluence than the national average in these two populations.

Table 4 Lifestyle and demographic characteristics of divers and offshore workers

	Divers (n = 1540)	***Offshore workers (n =1035)***	
Age *mean (95%CI)*	45.2 (44.7-45.7)	45.5 (45.1-45.9)	p=0.4
Smoking n (%)			
less than 100 cigarettes	702 (46%)	454 (44%)	p<0.001*
ex-smoker	525 (34%)	281 (27%)	
current smoker	305 (20%)	297 (29%)	
Pack years (current & ex-smokers) *median (IQR)*	11 (5-21)	19 (10-30)	p<0.001
Binge drinking n (%)			
never	215 (14%)	99 (9%)	p<0.001*
less than monthly	348 (22%)	185 (18%)	
1-9 x month	690 (45%)	548 (53%)	
10-20 x month	195 (13%)	148 (14%)	
more than 20 x month	79 (5%)	50 (5%)	
Educational qualifications n (%)			
none	252 (16%)	147 (14%)	p<0.001*
O' levels, Standard Grades, school certificate	683 (44%)	378 (37%)	
A' levels, Highers	136 (9%)	89 (9%)	
HNC or HND	199 (13%)	201 (19%)	
University degree	247 (16%)	202 (19%)	
Carstairs Scores *median (IQR)*	-1.9 (-2.9 – -0.6)	-1.9 (-3.1 – 0.1)	p=0.4
Body mass index (kg.m^{-2}) *median (IQR)*	26.1(24.4 - 28.4)	26.0 (24.1-28.7)	p=0.7

pack years = usual number of cigarettes smoked per day *times* numbers of years smoked *divided by* 20
* p = group differences based on chi-square test for the overall factor

Educational attainment: Overall the differences between divers and offshore workers for educational attainment was found to be statistically significant (Table 4), with divers less likely to have higher educational qualifications than offshore workers. The observed differences, however, were small. Higher educational qualifications were associated with a shorter duration of career, for both divers and offshore workers (correlation: divers r = -0.24, offshore workers r = -0.24).

4.1.3 Occupational history

Eighty eight percent of divers and 91% of offshore workers were in employment at the time of the study, although not necessarily in the diving or offshore industry. Divers and offshore workers had worked in their respective industries for similar periods of time, with 44% of divers and 47% of offshore workers having worked as divers or offshore, respectively for more than 15 years.

Diving experience: The mean (95% CI) duration of a professional diving career in this population was 14.9 (14.5-15.3) years, ranging from 1 to 44 years. Forty five percent of divers had not dived in the year before the survey was completed and they were classified as non-current divers. The median (interquartile range - IQR) time since the non-current divers had last dived professionally was 8 (4-13) years, with 28% not having dived for 8 or more years. Divers in this study had a wide range of diving experience using different diving techniques (Table 5), a reflection of the range of diving industries in which they had worked. Twenty four percent had worked using all the diving techniques described.

Sixty three percent of divers reported a diving related accident during their professional career (Table 5). Thirty-two percent of divers had suffered decompression illness (DCI).

Table 5 Diving techniques used and diving related accidents reported by divers

	Divers n (%)
Professional diving techniques used	
SCUBA diving (air or nitrox)	1441 (93%)
Surface decompression diving (air or nitrox)	1187 (77%)
Other air or nitrox dives (surface demand)	960 (62%)
Mixed gas bounce diving	648 (42%)
Saturation diving	653 (42%)
Recreational diving	1162 (75%)
Decompression illness	
None	970 (68%)
Pain only DCI but no neurological DCI	319 (22%)
Neurological DCI but no pain only DCI	47 (3%)
Both pain only and neurological DCI	98 (7%)
Cerebral gas embolism	18 (1%)
Other diving related accidents:	
Exposure to contaminated gas	534 (35%)
Loss of consciousness under pressure	112 (7%)
Underwater explosion	205 (13%)
Drilling mud burn	288 (19%)

Lost time (more than 3 days) accidents: Forty seven percent of divers compared with only 29% of offshore workers reported a lost time accident ($p<0.001$). Furthermore, of those who reported an accident, 49% of divers compared with only 31% of offshore workers reported more than one lost time accident.

***Welding*:** Twenty three percent of divers (n=358) and 5% of offshore workers (n=49) had worked as a welder. Offshore workers were more likely to have welded for longer than divers ($p=0.007$), with 27% of divers and 45% of offshore workers of those with welding experience having welded for more than 15 years. The majority of welders, both divers (90%) and offshore workers (94%), reported having suffered a welding related disease or accident.

4.1.4 General health - Symptoms

Divers were more likely than offshore workers to report symptoms, with 52% of divers compared with 44% of offshore workers reporting one or more symptoms ($p<0.001$) (Table 6). More divers reported suffering 'forgetfulness or loss of concentration', 'joint pain or muscle stiffness', 'impaired hearing' and 'back or neck pain'. They were less likely to report suffering from 'skin rash or itch' and 'cough or wheeze'. The greatest difference was found for the complaint of 'forgetfulness or loss of concentration', reported by 18% of divers compared with only 6% of offshore workers. After adjusting for lifestyle and demographic factors differences between divers and offshore workers 'cough or wheeze' and 'back or neck pain' was reduced to a non-significant level ($p>0.05$).

Head injury: Almost twice as many divers (17%) as offshore workers (9%) reported a head injury ($p<0.001$). This encompassed head injuries sustained both at work and outside the working environment. Head injury was associated with forgetfulness or loss of concentration. Furthermore, divers with a head injury (25%) were more likely than offshore workers with a head injury (6%) to report forgetfulness or loss of concentration.

Welding, lost time accidents and head injury related to symptoms: Welding, lost time accidents and head injury, all more common among divers, were significantly related to forgetfulness or loss of concentration, joint pain or muscle stiffness and impaired hearing in the study population taken as a whole (Table 7).

Table 6 Percent of divers and offshore workers reporting 'moderate or extreme' symptoms

Types of Symptoms:	***Divers (%)***	***Offshore workers (%)***	***Unadjusted Model OR (95% CI)***	***p***	***Adjusted Model OR (95% CI)***	***p***
Joint pain or muscle stiffness*	458 (30%)	219 (21%)	1.5 (1.3 - 1.8)	<0.001	1.5 (1.3 – 1.9)	<0.001
Back pain or neck pain*	476 (31%)	277 (27%)	1.2 (1.0 – 1.4)	0.03	1.2 (1.0 – 1.2)	0.09
Breathlessness	52 (3%)	50 (5%)	0.7 (0.5 – 1.0)	0.05	0.8 (0.5 – 1.3)	0.29
Cough or wheeze	52 (3%)	54 (5%)	0.6 (0.4 – 0.9)	0.02	0.7 (0.5 – 1.1)	0.18
Abdominal pain, diarrhoea, constipation or nausea	87 (6%)	46 (4%)	1.2 (0.9 – 1.8)	0.24	1.3 (0.9 – 1.9)	0.24
Muscle weakness or tremor	61 (4%)	33 (3%)	1.2 (0.8 – 1.9)	0.36	1.5 (0.9 – 2.5)	0.09
Unsteadiness when walking, dizziness or poor balance	26 (2%)	20 (2%)	0.9 (0.5 – 1.5)	0.60	1.3 (0.6 – 2.8)	0.44
Forgetfulness or loss of concentration**	274 (18%)	60 (6%)	3.4 (2.6 – 4.6)	<0.001	3.7 (2.7 – 5.0)	<0.001
Impaired vision (not corrected by spectacles)	54 (4%)	29 (3%)	1.2 (0.8 – 1.9)	0.37	1.2 (0.7 – 2.0)	0.42
Impaired hearing	239 (16%)	113 (11%)	1.5 (1.2 – 1.9)	0.002	1.5 (1.2 – 2.0)	0.002
Skin rash or itch	101 (7%)	97 (9%)	0.7 (0.5 – 0.9)	0.005	0.6 (0.4 – 0.8)	0.001

All models are adjusted for age, binge drinking, smoking and head injury, * also adjusted for Body Mass Index (BMI) ** also adjusted for education
OR = Odds ratio, 95% CI = 95% confidence interval.

Table 7 Welding, accidents and head injury related to the main symptoms in the total study population

Symptom	***Welding*** No (n=2168)	Yes (n=407)	Odds ratio (95%CI)*
Joint pain or muscle stiffness	522 (25%)	155 (39%)	1.8 (1.4-2.3) p<0.001
Forgetfulness or loss of concentration	234 (11%)	100 (25%)	2.4 (1.8-3.1) p<0.001
Impaired hearing	262 (13%)	90 (23%)	2.0 (1.5-2.6) p<0.001
	3-Day Lost Time Accident		
	No (n=1515)	*Yes (n=1024)*	*Odds ratio (95%CI)**
Joint pain or muscle stiffness	283 (19%)	380 (38%)	2.5 (2.0-3.0) p<0.001
Forgetfulness or loss of concentration	150 (10%)	180 (18%)	1.6 (1.3-2.1) p<0.001
Impaired hearing	162 (11%)	178 (18%)	1.7 (1.3-2.1) p<0.001
	Head Injury		
Symptom	*No (n=2137)*	*Yes (n=346)*	*Odds ratio (95%CI)**
Joint pain or muscle stiffness	507 (24%)	123 (37%)	1.8 (1.4-2.4) p<0.001
Forgetfulness or loss of concentration	248 (12%)	67 (20%)	1.7 (1.3-2.4) p<0.001
Impaired hearing	263 (13%)	69 (21%)	1.9 (1.4-2.6) p<0.001

*models adjusted for age, binge drinking and smoking, 'joint pain or muscle stiffness' also adjusted for BMI, 'forgetfulness or loss of concentration' also adjusted for education

The addition of welding and lost time accidents into the main logistic regression models comparing reported symptoms reduced the odds ratio (95% CI) for the comparison of divers and offshore workers: joint pain or muscle stiffness [1.1 (0.9-1.4) p=0.2], forgetfulness or loss of concentration [3.1(2.2-4.3) p<0.001] impaired hearing [1.2 (0.9-1.6) p=0.3] (compare results with Table 6). Thus, adjusting for these experiences, which were more common among divers but are not pressure related, only left the incidence of 'forgetfulness or loss of concentration' significantly different between divers and offshore workers.

Work as a welder and reported symptom differences: The prevalence of forgetfulness or loss of concentration is higher in divers who weld than non-diving welders (Table 8). Divers, however, did not have a longer welding career than non-diving welders since they had spent less time working as welders. The prevalence of cognitive complaint in welder divers is 11% higher (28%) than for non-welder divers (16%).

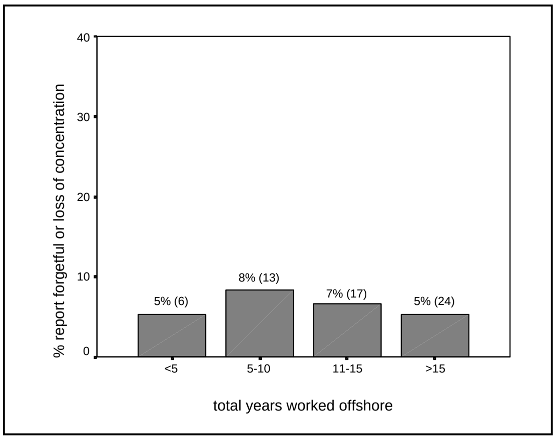
Working as a welder may be a risk factor in terms of cognitive complaint in divers. While diving and welding may be synergistic with regard to cognitive complaint the prevalence of musculoskeletal problems is just as high in non-diving welders as in diving welders and it may be that welding is the predominant influence here. Regarding hearing loss, the incidence of complaint is less in diving than in non-diving welders and it may be that diving has some protective effect (Table 8). The adverse effects of welding may be increased by diving. In addition to exposure to welding related toxins in an enclosed and potentially poorly ventilated underwater welding habitat, the effect of a high pressure environment must be considered.

Table 8 The frequency (%) of reported symptoms in divers, offshore workers and welder divers

	Offshore worker <u>not</u> welder (n=941)	***Offshore worker welder (n=47)***	***Diver <u>not</u> welder (n=1152)***	***Diver welder (n=351)***
Joint pain or muscle stiffness	20%	40%	27%	37%
Back or neck pain	27%	54%	29%	40%
Forgetfulness or loss of concentration	6%	**11%**	15%	**28%**
Impaired hearing	10%	32%	14%	21%

4.1.5 Forgetfulness or loss of concentration

***Duration of years worked in respective industries*:** The duration of a diver's career (p<0.001), but not offshore workers (p=0.5), was related to reported forgetfulness or loss of concentration (Figure 3).



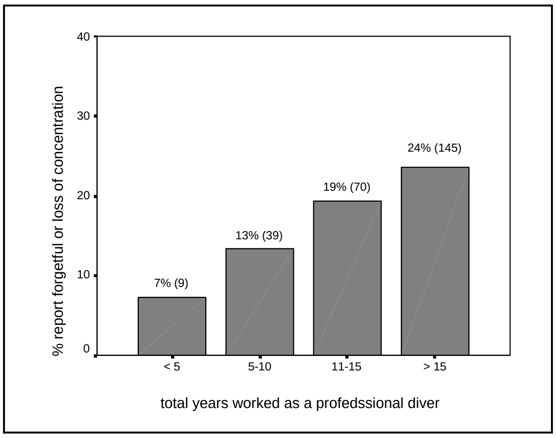


Figure 3 Relationship between reported 'forgetfulness or loss of concentration' and duration of offshore and diving careers (raw data)

Diving experience

There was no difference in the prevalence of reported forgetfulness or loss of concentration between the divers who were currently diving professionally (20%) and those who were not (18%).

Decompression illness: 52% of the forgetful divers compared with 32% of non forgetful divers reported having suffered DCI (p<0.001). The proportion of forgetful divers who reported having suffered pain only DCI but not neurological DCI (25%) and those who had suffered neurological and pain only (31%) did not differ significantly (p=0.11). Furthermore, the difference in the proportion of forgetful divers who reported suffering from DCI only once (22%) or more than once (30%) failed to reach a level of statistical significance at the 5% level (p=0.07). These comparisons suggest that having had DCI is an important factor with relation to reported forgetfulness, but the type of DCI and the number of events is less significant. There was no indication, therefore of a dose related effect. Forgetfulness or loss of concentration was not fully explained by DCI, since the difference between divers and offshore workers remained highly significant after including DCI in the logistic regression model (odds ratio (95% CI): 2.3 (1.6-3.3), p<0.001).

Diving techniques: As illustrated in Figure 4, reported forgetfulness was associated with increased experience of the diving technique for surface oxygen decompression dives, mixed gas bounce dives and days spent in saturation, but not SCUBA or other air/nitox (surface supply / demand with air or nitrox) diving.

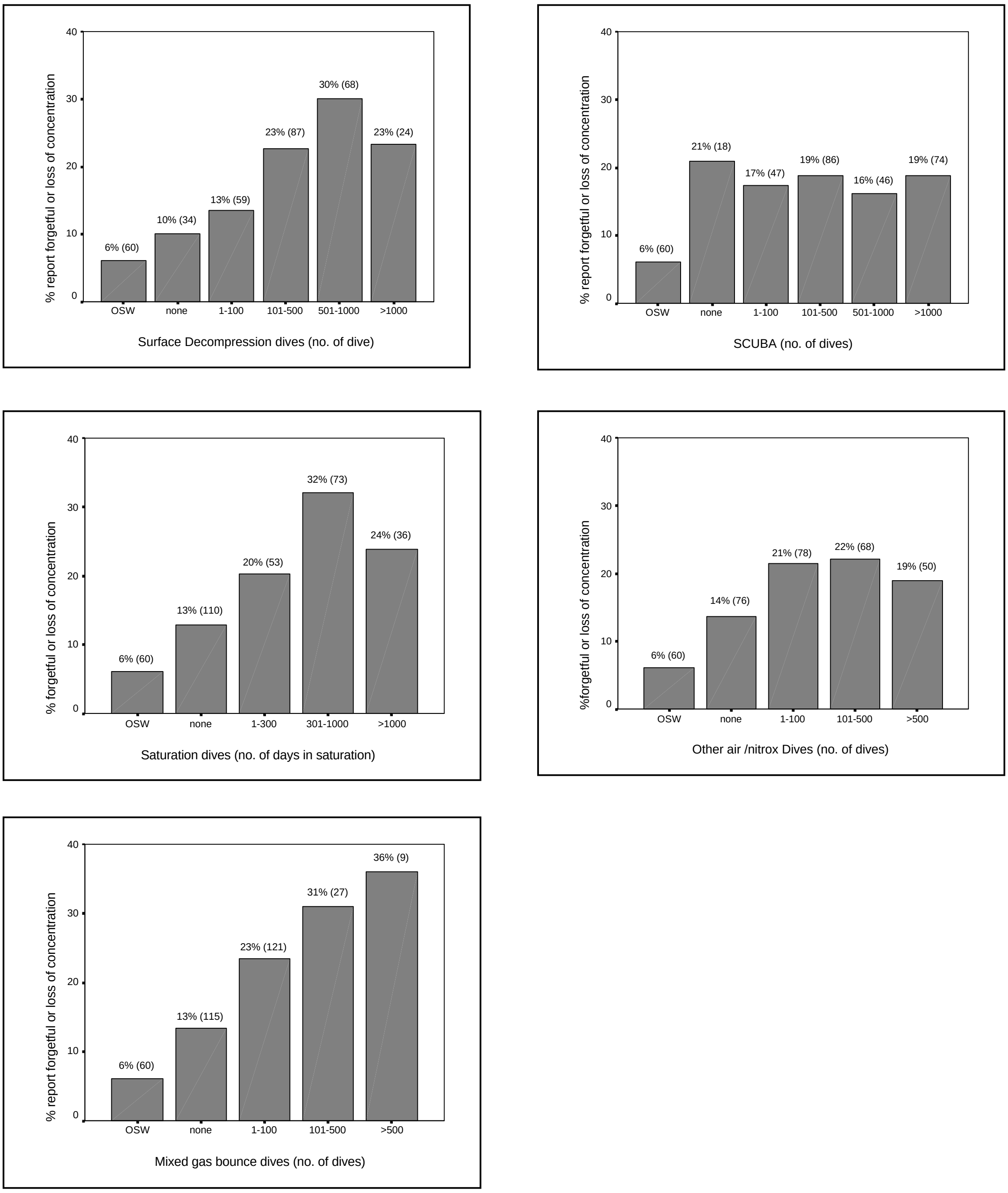


Figure 4 Percent (number) of divers reporting 'forgetfulness or loss of concentration' using different diving techniques (raw data)

A logistic regression model including each diving technique as a continuous variable was adjusted for lifestyle factors, head injury, welding and lost time accidents. The model showed a significant positive relationship between surface oxygen decompression diving, mixed gas bounce diving and saturation diving and reported ‘forgetfulness or loss of concentration’ (Table 9). The odds ratios are based per 100 dives or days in saturation. Since DCI was associated with forgetfulness, this was added to the logistic regression model. Adjustment for DCI resulted in the loss of the effect of surface oxygen decompression diving, but saturation diving and mixed gas bounce diving remained highly related to reports of forgetfulness or loss of concentration.

Divers who had only used SCUBA (n=183) did not differ significantly from offshore workers when reporting forgetfulness (9% vs. 6%, p=0.1). This difference remained the same when divers having only used SCUBA or surface demand (n=263) were compared with offshore workers. For those divers who had used all the techniques described, 20% reported forgetfulness or loss of concentration. The techniques associated with forgetfulness are those used predominantly in the offshore diving industry.

Table 9 Logistic regression models assessing the relationship between the amount of diving using different techniques and symptoms

	*Model 1**		*Model 2***	
	OR (95% CI)	*p*	*OR (95% CI)*	*p*
Forgetful or loss of concentration				
Main group (diver)	2.23 (1.52-3.28)	<0.001	1.98 (1.32-2.97)	0.001
Diving techniques (per 100 dives):				
Other air/nitrox dives (surface demand)	0.99 (0.96-1.01)	0.25	0.99 (0.94-1.02)	0.41
SCUBA	1.00 (0.98-1.02)	0.98	1.00 (0.98-1.03)	0.95
Surface decompression	1.04 (1.01-1.08)	0.02	1.03 (0.99-1.07)	0.10
Saturation days	1.04 (1.01-1.07)	0.01	1.04 (1.00-1.07)	0.02
Mixed gas bounce	1.27 (1.07-1.50)	0.006	1.22 (1.03-1.44)	0.02
Joint pain or muscle stiffness				
Main group (diver)	0.98 (0.74-1.30)	0.89	0.89 (0.66-1.19)	0.43
Diving techniques (per 100 dives):				
Other air/nitrox dives (surface demand)	1.04 (1.00-1.07)	0.04	1.04 (1.00-1.07)	0.05
SCUBA	0.99 (0.97-1.01)	0.17	0.99 (0.97-1.01)	0.21
Surface decompression	1.01 (0.98-1.04)	0.58	1.00 (0.97-1.04)	0.84
Saturation days	1.01 (0.98-1.04)	0.61	1.00 (0.98-1.03)	0.78
Mixed gas bounce	1.24 (1.06-1.45)	0.007	1.22 (1.04-1.42)	0.02
Impaired hearing				
Main group (diver)	0.93 (0.65-1.33)	0.69	0.91 (0.62-1.32)	0.61
Diving techniques (per 100 dives):				
Other air/nitrox dives (surface demand)	1.00 (0.96-1.05)	0.89	1.00 (0.96-1.05)	0.89
SCUBA	1.00 (0.98-1.03)	0.78	1.00 (0.98-1.03)	0.76
Surface decompression	1.01 (0.97-1.05)	0.68	1.01 (0.97-1.04)	0.73
Saturation days	1.05 (1.02-1.09)	0.002	1.05 (1.02-1.09)	0.003
Mixed gas bounce	1.03 (0.85-1.24)	0.78	1.02 (0.85-1.24)	0.81

* analysis adjusted for age, smoking, binge drinking, head injury, welding and lost time accidents.
** adjusted as for model 1 plus DCI

Other symptoms

Although the other 2 main symptoms, joint pain or muscle stiffness and impaired hearing, did not show a difference between divers and offshore workers after adjustments were made for work related factors (welding and accidents), their relationship with the use of different diving techniques was investigated (Table 9).

Joint pain or muscle stiffness

Adjustment for lifestyle and work related factors did not show a difference between divers and offshore workers, but there was a significant dose response with mixed gas bounce diving and 'other' air/nitrox (surface supply / demand with air or nitrox) dives for joint pain or muscle stiffness. The additional adjustment for DCI (see Table 9 model 2) did not alter the dose response relationships seen in model 1.

***Decompression illness*:** Divers reporting joint pain or muscle stiffness were more likely to have suffered DCI (49%) than those not reporting these symptoms (31%) ($p<0.001$). Of the divers having suffered DCI, the same proportion reporting and not reporting joint pain or muscle stiffness had suffered pain only DCI but not neurological DCI (72% *vs.* 70%) and neurological DCI (with or without pain only DCI) (28% *vs*. 30%) ($p=0.7$). Divers with joint pain or muscle stiffness were more likely to have suffered more than one episode of DCI (pain only or neurological) (26%) than those without joint pain (14%) ($p<0.001$). This suggests, from this limited data, that there might be a dose response with DCI and reported joint pain or muscle stiffness.

Impaired hearing

As seen with joint pain and muscle stiffness, there was no difference between divers and offshore workers for impaired hearing after adjustments for lifestyle and work related factors, but there was a significant dose relationship with saturation diving. Adjustment for DCI did not alter the dose response with saturation diving.

Decompression illness: Divers reporting impaired hearing (48%) were more likely to have suffered DCI than divers not reporting impaired hearing (34%) ($p<0.001$). These two groups did not differ significantly in the type of DCI suffered ($p=0.1$). Of those reporting DCI, 36% of divers with impaired hearing had suffered neurological DCI compared with 28% not reporting hearing impairment. Impaired hearing, however, did not appear to be associated with increased incidence of DCI ($p=0.2$).

4.1.6 Medical Conditions

51% of both divers and offshore workers reported to have been diagnosed with one or more medical conditions. Individual diagnosed medical conditions are summarised in Table 10. Unadjusted data showed that divers were more likely than offshore workers to have arthritis and less likely to have asthma and high blood pressure. After adjusting the models for lifestyle and demographic attributes, however, the only conditions to differ between divers and offshore workers were asthma, high blood pressure and stroke.

Table 10 Percent of divers and offshore workers reporting having been diagnosed with a medical conditions

Types of medical conditions:	*Divers*	*Offshore workers*	*Unadjusted*		*Adjusted**	
	(%)	*(%)*	*OR (95% CI)*	*p*	*OR (95% CI)*	*p*
Diabetes	19 (1%)	13 (1%)	1.0 (0.5 – 2.0)	0.92	0.8 (0.4 – 1.9)	0.69
Heart attack or disease	31 (2%)	27 (3%)	0.8 (0.5 – 1.3)	0.29	0.6 (0.3 – 1.2)	0.15
Stroke	7 (0.5%)	6 (0.6%)	0.8 (0.3 – 2.3)	0.64	0.1 (0.3 – 0.7)	0.02
High blood pressure	156 (10%)	129 (13%)	0.8 (0.6 – 1.0)	0.05	0.7 (0.6 – 1.0)	0.03
Migraine	105 (7%)	77 (7%)	0.9 (0.7 – 1.2)	0.48	0.9 (0.6 – 1.2)	0.34
Epilepsy	7 (0.5%)	6 (0.6%)	0.8 (0.3 – 2.3)	0.64	0.5 (0.1 – 1.8)	0.30
Cancer (including leukaemia)	30 (2%)	20 (2%)	1.0 (0.6 – 1.8)	0.98	0.9 (0.5 – 1.7)	0.76
Ulcer (stomach or peptic)	91 (6%)	72 (7%)	0.8 (0.6 – 1.2)	0.26	0.8 (0.6 – 1.2)	0.27
Dermatitis	145 (9%)	95 (9%)	0.9 (0.8 – 1.3)	0.93	1.0 (0.7 – 1.3)	0.77
Eczema or hayfever	237 (15%)	152 (15%)	1.0 (0.8 – 1.3)	0.78	1.0 (0.8 – 1.3)	0.92
Chronic bronchitis or other lung disease	59 (4%)	41 (4%)	1.0 (0.6 – 1.4)	0.81	0.9 (0.6 – 1.4)	0.57
Asthma	78 (5%)	73 (7%)	0.7 (0.5 – 1.0)	0.03	0.6 (0.5 – 0.9)	0.02
Depression or anxiety	140 (9%)	96 (9%)	1.0 (0.7 – 1.3)	0.77	0.9 (0.7 – 1.3)	0.66
Arthritis	136 (9%)	64 (6%)	1.4 (1.1 – 2.0)	0.02	1.3 (0.9 – 1.8)	0.13
Vibration white finger	38 (3%)	25 (2%)	1.0 (0.6 – 1.7)	0.98	0.9 (0.5 – 1.6)	0.83

* analysis adjusted for age, smoking, binge drinking and head injury

4.1.7 Health Related Quality of Life (SF-12)

The mean scores for both physical (PCS) and mental (MCS) components were similar for both divers and offshore workers (Table 11). These scores are comparable to population means, based on a male population from the Oxford Healthy Lifestyle Survey (OHLS) (63). The small difference between divers and offshore workers for MCS was not significant when adjusted for lifestyle factors.

Table 11 PCS and MCS scores for divers and offshore workers (mean (SD))

	Divers	*Offshore workers*	*Unadjusted comparison*	*Adjusted comparison**	*OHLS (men)*	*Standard popn. mean*
PCS	52.1 (7.9)	52.0 (7.6)	p=0.7	p=0.9	51.2 (9.2)	50 (10)
MCS	51.6 (9.1)	50.7 (9.4)	p=0.01	p=0.09	51.4 (8.9)	50 (10)

* analysis adjusted for age, smoking, binge drinking and head injury

Factors predicting HRQOL

HRQOL and lifestyle: A lower PCS score was associated with increased age, being a current smoker and lower educational attainment (less than A' level qualifications). Lower PCS was associated with higher BMI in divers, but not offshore workers. Lower MCS scores were associated with younger age, current smoking, binge drinking (>20x month) and being divorced or widowed. Higher educational attainment was associated with higher MCS in divers but not offshore workers. Head injury was associated with lower PCS and MCS scores of offshore workers but appeared to have relatively little impact on divers. The associations described above were all statistically significant, but the mean reduction in HRQOL scores ranged from 1 to 5, which is only marginally clinically significant.

HRQOL and work related factors: The two main non-diving factors related to the work environment were welding and 3-day lost time accident at work. Welding was associated with lower PCS scores in offshore workers but not divers. There was no association with MCS. It was not possible to separate the impact of welding accident from welding *per se* since 90% of divers and 95% of offshore workers who had welded reported to have suffered a welding accident.

3-day lost time accidents were associated with lower PCS and MCS scores in both divers and offshore workers, but the impact of having more than once lost time accident was greater in offshore workers (Figure 5). It was not possible to determine from the questionnaire survey if the 3-day lost time accidents experienced by offshore workers were similar in nature to that of divers. The results from Part 2 of the study, however, showed that in the 10% random sample of divers, 63% of the reported 3-day lost time accidents were diving related. This difference could be confounding the comparison of 3-day lost time accidents on HRQOL between divers and offshore workers. In an attempt to evaluate this issue the analysis was repeated eliminating all divers who had experienced a diving related accident (including DCI, cerebral gas embolism, exposure to contaminated gas, loss of consciousness under pressure and exposure to underwater explosions), since some of these could have also been classified 3-day lost time accident. Of the 591 divers who had not suffered a diving related accident, it was assumed that the 3-day lost time accident suffered by the 221 divers remaining in this group were not diving related and the nature of these accidents might be more comparable with those of offshore workers. Excluding these divers did not alter the relationship between lost time accident and PCS. The relationship between lost time accidents and MCS was lost, suggesting that in divers the effect seen with MCS may be the result of dive related accidents.

The increased difference in HRQOL between divers and offshore workers having experienced 'more than one' lost time accident might also be explained by individual offshore workers in this group having experienced many more accidents than divers in the 'more than one' category. This information again was not available from the questionnaire survey in Part 1. Data from the random sample in Part 2, however, would not support this theory since the distribution of the number of 'more than one' 3-day accident was similar for both divers and offshore workers.

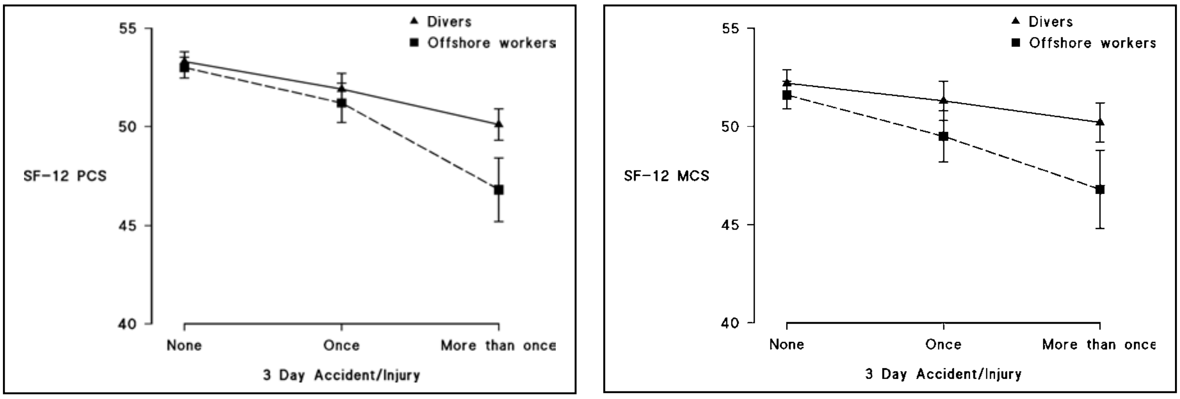


Figure 5 Impact of 3-day lost time accidents on HRQOL (PCS and MCS)

HRQOL and diving experience: Longer diving careers were related to higher PCS (p=0.04) and MCS (p=0.05). This, however, may be due to the fact that the divers who continue to dive professionally have not suffered from other events that impact negatively on HRQOL, such as accidents or a medical condition. The only diving technique to show a significant relationship with HRQOL was mixed gas bounce diving, which was associated with a lower PCS (p=0.04). Divers having experienced neurological DCI, cerebral gas embolism and exposure to contaminated gas had lower MCS compared with those divers who had not suffered these accidents. Being exposed to an underwater explosion was associated with lower PCS.

HRQOL and diagnosed medical conditions: Having a diagnosed medical condition was associated with a significantly lower PCS and MCS. The majority of conditions had a greater impact on PCS than on MCS, with the exception of depression or anxiety, dermatitis and asthma for which the impact was greater on MCS than PCS. Arthritis and heart disease appeared to have the greatest impact on the PCS of both divers and offshore workers, and depression or anxiety has the greatest impact on MCS. Table 12 shows the effect size on HRQOL associated with diagnosed medical conditions where there was a statistically significant difference between those with and without the condition. The effect size for these conditions was of the magnitude that would be deemed as clinically significant. An effect size of less than 0.2 might be interpreted as having little impact on day to day life.

Table 12 Effect size on the SF-12 associated with diagnosed medical conditions

	Effect size (d)	
	SF-12: PCS	***SF-12: MCS***
Depression or anxiety	0.67	1.15
Arthritis	1.01	ns
Heart attack or disease	1.02	ns
High blood pressure	0.54	0.24
Cancer	0.56	ns
Ulcer	0.32	0.22
Dermatitis	ns	0.25
Eczema or hayfever	ns	0.14
Chronic bronchitis	0.70	0.24
Migraine	0.55	0.19
Asthma	ns	0.36
Diabetes	0.69	ns
Vibration white finger	0.38	ns

ns= HRQOL scores were not statistically significantly different between those with and without the medical condition

HRQOL and reported symptoms: Reporting any one of the symptoms listed in the questionnaire was associated with significantly lower PCS and MCS scores of both divers and offshore workers.

Only the symptoms that differed between divers and offshore workers were used in the following analysis that explores what factors impact on the HRQOL of divers and offshore workers. Those subjects reporting forgetfulness or loss of concentration, joint pain or muscle stiffness and impaired hearing had lower PCS and MCS. There were, however, interactions found between the two populations and reported symptoms, suggesting the impact of these symptoms on HRQOL differs between divers and offshore workers. Forgetfulness or loss of concentration and joint pain or muscle stiffness appeared to have a greater impact on MCS in offshore workers than divers. Joint pain or muscle stiffness had a similar impact on PCS in both groups. Impaired hearing had a greater impact on PCS in offshore workers than in divers. Table 13 shows the effect size of the difference in PCS and MCS for divers and offshore workers with and without these reported symptoms. The effect size was comparable to those seen in individuals with diagnosed medical conditions. This lent support to the conclusion that these symptoms would affect day to day quality of life.

Table 13 Effect size on the SF-12 associated with symptoms reported by divers and offshore workers

	SF-12: PCS		***SF-12: MCS***	
	Divers	***Offshore workers***	***Divers***	***Offshore workers***
Forgetfulness or loss of concentration	0.45	0.91	0.66	1.48
Joint pain or muscle stiffness	0.85	0.90	0.37	0.59
Impaired hearing	0.36	0.76	0.24	0.33

4.1.8 What factors impact HRQOL of divers and offshore workers?

As described previously, divers were more likely to suffer complaints of forgetfulness or loss of concentration, joint pain or muscle stiffness, impaired hearing, head injury and lost-time accidents, all of which have been shown to be associated with lower HRQOL. In view of this, it was surprising to observe that the HRQOL of divers, adjusted for lifestyle factors, did not differ from offshore workers (Table 11). There are two explanations proposed for this paradox. Either the impact of these individual factors on HRQOL is less in the diving population or HRQOL in the diving population is originally higher than offshore workers but more divers suffer the factors limiting HRQOL.

This paradox was explored using multiple linear regression analysis to establish individual factors and their relative importance in HRQOL of divers and offshore workers. The analysis also addressed the issue of whether diving *per se* is more or less important than other work and lifestyle factors in determining HRQOL in divers.

Physical HRQOL (PCS): Table 14 presents the independent contributions of the lifestyle and work related factors included in the final linear regression model. Factors included in the model were those shown to have statistically significant relationship in the univariate analysis. The initial unadjusted comparison of divers and offshore workers did not explain any variance in PCS. Lifestyle factors explained 6.7% of the variance in PCS and this increased to 9.8% with the inclusion of work related factors.

Increasing age and being a current smoker has a significantly negative impact on PCS. While the other lifestyle factors that contribute to the PCS were not statistically significant in this model. The only lifestyle factor to have a significantly different impact on divers and offshore workers was BMI, with increased BMI having a greater impact on divers than offshore workers.

Having worked as a welder and experienced more than one 3-day lost time accident was associated with lower PCS. Having more than one 3-day accident had less impact on divers than offshore workers as illustrated by the significant interaction term (lost time accident *diver). A cerebral gas embolism has a large negative impact on PCS. Within this model, 3-day lost time accidents, working as a welder and having suffered a cerebral gas embolism had the greatest impact on PCS. Only 9.7% of the variance is, however, explained by these factors, which means there many other influential factors that have not been accounted for in the model explaining PCS.

Including the symptoms that differed between divers and offshore workers into the above model increased the variance accounted for in PCS to 20.0%. Forgetfulness or loss of concentration (regression coefficient (95% CI) = -2.4 (-4.5 – -0.2), p=0.03), joint pain or muscle stiffness (-5.1 (-6.3 – -3.8), p<0.001) and impaired hearing (-3.1 (-4.7 – -1.5), p<0.001) were all significant predictors of PCS. The interaction observed between divers/offshore workers and impaired hearing (2.5 (0.4 – 4.5), p=0.02), suggests that impaired hearing had a greater negative impact on PCS of offshore workers than of divers. There were no interactions observed for the other two symptoms suggesting that they have a similar impact on PCS in both groups. The addition to the model of a factor for suffering from any diagnosed medical condition only increased the variance explained to 21.5%.

Table 14 Linear regression model predicting PCS and MCS

	Predicting PCS		***Predicting MCS***	
	Regression Coefficient (95%CI)	*p-value*	*Regression Coefficient (95%CI)*	*p-value*
Diver	1.1 (-4.6 – 6.9)	0.7	3.8 (-1.4 – 9.0)	0.2
Lifestyle:				
Age (per 5 yrs)	-1.0 (-1.3 – -0.7)	<0.001	0.7 (0.3 – 1.2)	<0.001
Current smoker	-1.6 (-2.7 – -0.5)	0.004	-1.1 (-2.5 – 0.3)	0.1
Educational attainment (≥ A'level)	0.2 (-0.2 – 0.5)	0.3	-0.1 (-0.6 – 0.3)	0.5
BMI	-0.1 (-0.2 – 0.02)	0.1	*not in model*	
Binge drink (>20x per month)	0.7 (-1.6 – 2.9)	0.6	-3.1(-6.1 – -0.1)	0.04
Carstairs score	-0.1 (-0.2 – 0.2)	0.9	0.1 (-0.2 – 0.4)	0.4
Divorced or widowed	*not in model*		-2.4 (-3.9 – -0.9)	0.002
Head injury	-0.8 (-2.5 – 0.9)	0.4	-2.8 (-5.0 – -0.6	0.01
Age*diver	0.3 (-0.2 – 0.7)	0.2	-0.3 (-0.8 – 0.3)	0.4
Current smoker*diver	-0.2 (-1.7 – 1.4)	0.8	-2.3 (-4.3 – -0.3)	0.03
Educational*diver	-0.2 (1.4 – 1.0)	0.7	-0.8 (-2.4 – 0.7)	0.3
BMI*diver	-0.2 (-0.3 – -0.001)	0.05	*not in model*	
Binge drink*diver	-1.6 (-4.6 – 1.4)	0.3	-1.2 (-5.2 – 2.7)	0.5
Carstairs*diver	-0.3 (-0.6 – -0.05)	0.1	0.1 (-0.3 – -0.5)	0.6
Head injury*diver	0.6 (-1.4 – -2.6)	0.6	2.9 (0.2 – 5.5)	0.03
Work related:				
Welder	-2.8 (-5.3 – -0.03)	0.03	1.9 (-1.2 – 5.1)	0.2
> one 3-day lost time accident	-4.7 (-6.5 – -2.9)	<0.001	-4.4 (-6.8 – -2.1)	<0.001
Duration of diving career (per 5 yrs)	0.3 (-0.03 – -0.6)	0.07	0.3 (-0.1 – 0.7)	0.2
Cerebral gas embolism	-5.1 (-9.2 – -0.9)	0.02	-4.4 (-9.8 – 0.9)	0.1
Underwater explosion	-0.9 (-2.2 – -0.3)	0.2	*not in model*	
Contaminated gas	*not in model*		-1.7 (-2.9 – -0.5)	0.005
Neurological DCI	*not in model*		-2.3 (-4.2 – -0.4)	0.02
Welder*diver	2.3 (-0.4 – 5.0)	0.1	-2.9 (-6.4 – 0.5)	0.1
3-day lost time accident*diver	2.6 (0.6 – 4.7)	0.01	2.8 (0.1 – 5.5)	0.05

Note: Interaction term = 'factor'*diver

Mental HRQOL (MCS): The unadjusted difference in MCS scores between divers and offshore workers only explained 0.1% of the variance. Including lifestyle factors explained 4.9% of the variance in MCS and the addition of work related factors into the model increased the variance explained to 7.3% (Table 14).

Older subjects were more likely to have higher MCS scores, while binge drinking more than 20 times per month and being divorced or widowed was associated with decreased MCS. A number of lifestyle factors had a different impact on MCS for divers and offshore workers, as illustrated by the interaction terms in the model. Being a current smoker had a greater negative impact on divers than offshore workers. Conversely, the effect of a head injury on MCS was greater in offshore workers than divers.

As seen for PCS, 3-day lost time accidents had a significant impact on MCS of both divers and offshore workers, again with the effect being greater in offshore workers than divers. Welding was not associated with MCS. Among divers, neurological DCI and exposure to contaminated gas had a significant negative impact on MCS.

The inclusion in the model of symptoms increased the variance explained to 15.3%. The complaint of forgetfulness or loss of concentration contributed most to this increase (-11.1 (-13.9 - -8.3), p<0.001) and the impact of this complaint was greater for offshore workers than divers (interaction term: 6.4 (3.3-9.6), p<0.001). Joint pain or muscle stiffness (-3.6 (-5.2 - -1.9), p<0.001), but not impaired hearing (-0.6 (-2.7 - -1.5), p=0.5) had a significant negative impact on MCS, but this did not differ between divers and offshore workers. Including a factor for suffering a diagnosed medical condition only increased the variance explained to 16.5%.

HRQOL of divers and offshore workers without symptoms: Excluding divers and offshore workers who reported suffering from the three main symptoms, as expected, showed an increased mean (SD) PCS and MCS for the remaining 824 divers (PCS: 53.3 (7.3), MCS: 54.3 (5.0)) and 669 offshore workers (PCS: 52.1 (8.0), MCS: 53.7 (5.5)) who did not complain of these symptoms. After adjusting for age, there was still no significant difference in these scores between divers and offshore workers.

HRQOL of divers and offshore workers not having suffered an accident or worked as a welder: Excluding divers and offshore workers suffering diving related accidents (including DCI), 3-day lost time accidents or working as a welder led to a higher mean (SD) PCS score for the remaining 319 divers (PCS: 53.5 (6.7), MCS: 52.9 (8.6)) and 656 offshore workers (PCS: 53.1 (6.3), MCS: 51.4 (8.9)). Again after adjusting for age, there was still no significant difference between divers and offshore workers.

Excluding subjects who had any of the work related factors that reduced HRQOL and any of the three symptoms studied and symptoms reducing HRQOL, only left 250 divers (16%) and 512 offshore workers (49%). Within this remaining sample, however, there was no significant difference in PCS or MCS between divers and offshore workers.

A greater proportion of divers than offshore workers have suffered the factors associated with lower HRQOL. It would appear, however, from this analysis that the impact of these factors on HRQOL is less for individual divers than it is for individual offshore workers. Furthermore, excluding subjects as described above did not reveal a higher HRQOL in divers than in offshore workers. This indicates that HRQOL is not higher in divers before they suffer an accident or develop symptoms.

4.2 PART 2: CLINIC STUDY

4.2.1 Response rate

A total of 233 divers and 120 offshore workers completed the clinic study (Part 2) (Table 15). A greater proportion of the divers (41%) than offshore workers (23%) contacted agreed to participate in the clinic study. Forgetful divers without a head injury were more likely to attend the study (55%) than non-forgetful divers without head injury (31%). The lowest response rate was among forgetful offshore workers without a head injury (17%).

Table 15 Response rate of those invited to participate in the clinic study (Part 2)

	Divers (n)	***Offshore workers (n)***
Attended Part 2	233 (41%)	120 (23%)
Declined to take part	98 (17%)	200 (39%)
No response	207 (36%)	169 (33%)
Wrong address	32 (6%)	29 (5%)
Other*	4 (<1%)	0 (0%)
Total selected	574	518

* included individuals who had died and one woman (this information was missing on the original questionnaire)

4.3 PHASE 1B: COMPARISON OF DATA FROM THE CLINIC STUDY WITH THE QUESTIONNAIRE SURVEY

The initial stage of phase 1b was to compare the questionnaire data from Part 1 against the objective measurements made in Part 2. This was achieved by studying a 10% random sample of those who completed phase 1a. It should be noted, however, that there was a time lag of 1 to 2 years between participating in Part 1 and 2 and some of variables measured would be sensitive to such a time change.

The sample in phase 1b was stratified for age, head injury and reported forgetfulness or loss of concentration. This 10% random sample was also representative of the phase 1a population, with regards to work status, lost time accidents, diving experience and welders (Table 16). Approximately half of the diving population (46%) was actively working in diving at the time of participation in the clinic study, with the remaining 44% having permanently given up professional diving and 8% not currently working but planning to return to a diving career. These ratios were similar to the whole population in the questionnaire survey.

Table 16 Characteristics of divers and offshore workers recruited for the clinic study (random sample: phase 1b) compared with the total sample from the questionnaire survey (phase 1a)

	Divers (n=1540) phase 1a	*Divers (n=151) phase 1b*	*Offshore workers (n=1035) phase 1a*	*Offshore workers (n=102) phase 1b*
Age (years) mean 95% CI	45.5 (45.1-45.9)	45.5 (44.2-46.8)	45.2 (44.7-45.7)	45.3 (43.8-46.8)
Duration of career as diver or offshore worker				
<5 years	10	6	11	5
6-10 years	19	16	16	13
11-15 years	24	29	26	29
>15 years	41	43	47	53
missing data	6	6	0	0
3-day lost time accident (%)				
None	52	53	70	69
One	24	24	21	19
More than one	24	23	9	12
Current diver (%)	48	42	-	-
Welder (%)	23	21	5	6
SCUBA (%)				
None	4	2	100	100
1-100 dives	18	15		
101-500 dives	30	32		
501-1000 dives	19	20		
>1000 dives	26	29		
missing data	3	2		
Surface decompression (%)				
None	17	17	100	100
1-100 dives	29	28		
101-500 dives	26	24		
501-1000 dives	15	15		
>1000 dives	7	9		
missing data	6	7		
Other air/nitrox dives (%)				
None	22	18		
1-100 dives	24	26		
101-500 dives	20	18		
>500 dives	18	20		
missing data	16	17		
Mixed gas bounce dives (%)				
None	43	45	100	100
1-100 dives	34	37		
101-500 dives	6	4		
>500 dives	2	2		
missing data	15	12		
Saturation dives (%)				
None	44	45	100	100
1-300 days	17	13		
301-1000 days	15	17		
>1000 days	10	13		
missing data	14	12		

Table 16 continued overleaf

Table 16 continued

	Divers (n=1540) phase 1a	*Divers (n=151) phase 1b*	*Offshore workers (n=1035) phase 1a*	*Offshore workers (n=102) phase 1b*
Pain only DCI (%)				
Never	66	66	100	100
Once	16	19		
More than once	16	13		
missing data	2	2		
Neurological DCI (%)				
Never	84	86	100	100
Once	8	6		
More than once	3	3		
missing data	5	5		
Symptoms (%)				
Forgetfulness or loss of concentration	18	18	6	7
Joint pain or muscle stiffness	30	35	21	26
Impaired hearing	16	21	11	13

The sampling criteria for divers and offshore workers differed slightly in the questionnaire survey. While divers were selected on the basis of having registered to work before 1991, offshore workers were selected on the basis of having a fitness to work medical examination in 1990, 1991 or 1992. This difference may add bias to the study because there may have been a tendency to sample older divers who had been in their career longer. The questionnaire survey did not establish duration of offshore worker career beyond 15 years. Since the Phase 1b random sample was representative of the population, career duration was compared using data from this sample. Duration of career did not differ between people who had stopped diving or had left the offshore industry (Table 17), although divers tended to start their career earlier than offshore workers. This might well have been caused by the difference in sample selection between groups but is unlikely to introduce bias.

Divers stopped diving at an earlier age than offshore workers left the offshore industry and while 72% of offshore workers were still working in the offshore industry only 47% of divers were still actively diving (Table 17). Both age and occupational status can introduce bias in HRQOL measurement and so health related quality of life was compared between groups, allowing for these factors using analysis of covariance. The mental health component of the SF-12 questionnaire score was unaffected. The physical component, however, was lower in people that had left their respective industries and somewhat lower again in the offshore worker group than in divers. These effects, however, were due to age rather than group or occupational status and, since age had been included in our analysis of HRQOL there would be no bias from this source.

Furthermore, within the random sample there was the same proportion of ‘forgetful’ divers and ‘non forgetful’ divers still working in the diving industry (50% *vs*. 48%).

Table 17 Duration of career of divers and offshore workers who were currently working in or had left the industry at the time of the clinic study

	Age mean (95% CI)	*Career duration* mean (95%CI)	*Date started work in the industry* mean (95% CI)	*Date last worked in the industry* mean (95%CI)
Divers				
Stopped permanently n=65 (44%)	48.6 (46.5-50.6)	16.6 (14.6-18.6)	1976 (1974-1978)	1993 (1992-1995)
Stopped temporarily n=13 (9%)	48.1 (43.4-52.7)	16.9 (12.6-21.3)	1980 (1976-1984)	1998 (1995-2000)
Still working as a diver n=70 (47%)	45.1 (43.3-46.9)	18.1 (16.3-20.0)	1981 (1979-1983)	2000 (1999-2001)
Offshore workers				
Stopped permanently n=23 (22%)	52.9 (49.4-56.5)	16.0 (13.2-18.9)	1979 (1977-1982)	1997 (1995-1998)
Stopped temporarily n=6 (6%)	42.5 (33.0-52.0)	12.8 (5.0-20.5)	1985 (1980-1990)	1998 (1993-2002)
Still working offshore n=73 (72%)	45.2 (43.8-46.7)	19.7 (16.5-19.3)	1982 (1981-1983)	2001 (2001-2002)

Lifestyle characteristics: Two of the key lifestyle factors relating to health are smoking and binge drinking alcohol. Smoking data reported in Part 1 and 2 was found to be highly reliable (kappa=0.84), but binge drinking information less reliable (kappa=0.44). Binge drinking, however, is likely to be sensitive to change over a significant time period.

4.3.1 Head injury

The majority of divers (81%) and offshore workers (74%) were consistent in their reporting of head injury. Inconsistencies tended to be associated with under-reporting in the questionnaire survey (Part 1), which was more common among offshore workers than divers. Table 18 shows the number of divers and offshore workers reporting a severe head injury, defined in this study as a head injury leading to loss of consciousness of at least 1 hour (LOC ≥ 1hr). This information was not available from the postal questionnaire. The severity of head injury (LOC ≥ 1hr) of those who did not report a head injury in the questionnaire survey did not differ between divers and offshore workers.

Table 18 Head injuries reported in Part 1 and 2 of the study

Diver			*Head injury - Part 2*			*LOC ≥ 1hr*	
			Yes	***No***	***Kappa***	***Yes***	***No***
	Head injury – Part 1	***Yes***	19	5	0.46	2	20
		No	23	97		4	116
OSW			*Head injury - Part 2*			*LOC ≥ 1hr*	
			Yes	***No***	***Kappa***	***Yes***	***No***
	Head injury - Part 1	***Yes***	8	0	0.30	3	5
		No	25	63		2	84

LOC ≥ 1 hour = head injury with loss of consciousness for one or more hours (note: this information was not collected in Part 1)

4.3.2 Neuropsychological testing

The following section demonstrates the objective support for the complaint of forgetfulness or loss of concentration reported in the questionnaire survey.

4.3.3 Subjective neuropsychological assessments

The different levels of ‘forgetfulness or loss of concentration’ (not at all, slight, moderate or severe) in the questionnaire survey were moderately correlated with the more detailed self-report measures of memory and cognitive function employed in the clinic study (Table 19).

Table 19 Correlations of subjective neuropsychological measures and ‘forgetfulness or loss of concentration’ in the questionnaire survey

	Pearson correlation with reported ‘forgetfulness’	
Prospective Retrospective Memory Questionnaire (n=224)	0.42	$p<0.001$
Cognitive Failure Questionnaire (n=221)	0.43	$p<0.001$
Dysexecutive Function Questionnaire (n=223)	0.31	$p<0.001$

4.3.4 Objective neuropsychological assessments

The relationship between objective neuropsychological tests and the 4 level ‘forgetfulness or loss of concentration’ question was weaker than that for the subjective questionnaires. Weak correlations were significant for Logical Memory (immediate recall: $r = -0.17$, $p=0.01$ and delayed recall: $r = -0.15$, $p=0.02$), SWM ($r = 0.13$, $p=0.04$) and RVP ($r = -0.22$, $p=0.001$). These results suggest that those subjects reporting increasing severity of forgetfulness or loss of concentration performed less well on objective tests of both memory and attention. Executive tasks without a strong memory component and general intellectual function were not significantly associated with ‘forgetfulness’ reported in the postal survey.

Further analysis compared forgetful subjects (moderate or severe forgetfulness) and non-forgetful subjects (non or mild forgetfulness) classified in the questionnaire survey. In an analysis considering the whole battery of neuropsychological objective tests together (MANOVA), forgetful subjects overall performed less well than non-forgetful subjects. Specifically, forgetful subjects performed significantly less well on memory (Logical Memory immediate recall ($p<0.001$), Logical Memory delayed recall ($p<0.001$), 5 Choice Reaction Time ($p=0.03$), SRM ($p=0.004$), SWM ($p=0.03$)) and concentration tests (RVP ($p<0.001$)).

Non-complainers with neuropsychological abnormalities: Abnormality (below 1.65 SD) for neuropsychological testing was assessed only for those tests with a significant memory or concentration component. The level of abnormality was deliberately selected for an incidence rate of 5% in the general population. The percentage incidence of abnormality in non-complainers remained below this rate in all the tests.

The level of abnormality tended to be higher in forgetful subjects than non-forgetful subjects, but in the overall study population the percentage of this sample showing abnormality remained very close to, or below, the 5% level suggesting no difference between this population and the general population in the prevalence of abnormality.

The impact of head injury on neuropsychological test results: The analysis was repeated excluding subjects with significant head injury (LOC ≥ 1 hour or unknown). Results showed that only 1 person from the spatial working memory (SWM) non-complaining abnormality sample was excluded from the analysis. This suggests that the abnormalities observed in this group were not accounted for by head injury.

4.3.5 Medical complaints

Symptoms reported in the questionnaire survey (Part 1 - see Table 6) were compared against symptoms reported in the medical examination (Part 2). Kappa values ranged from 0.27 (skin rash/itch) to 0.59 (impaired hearing). The values for the three main symptomatic differences found in the questionnaire survey (Part 1) are shown in Table 20. The time period between the two parts of the study, however, may have influenced the level of agreement, with the differences being due to a time lag rather than poor data reliability.

Table 20 Consistency (kappa values) of reported symptoms in the questionnaire survey (Part 1) and the clinic study (Part 2)

		Part 2		***kappa***
		yes	no	
	Part 1			
Joint pain or muscle stiffness	yes	37	44	0.36
	no	21	151	
Forgetfulness or loss of concentration	yes	17	17	0.44
	no	15	199	
Impaired hearing	yes	21	22	0.59
	no	2	203	

Hearing impairment: Self reporting of hearing problems in Part 1 and 2 was consistent as indicated by the kappa value (0.59). Further, contemporaneous, comparisons were made within the clinic study between the reported complaint in the medical examination (moderate or severe) and the objective measurements of hearing (moderate or severe abnormality). The specificity was high (0.98) indicating that subjects were able to accurately assess when their hearing was normal. Sensitivity, however, was only 0.15 suggesting that the majority of people with a hearing impairment were not aware of this or did not report it as a symptom. Only 21 (15%) people with an actual abnormality subjectively reported a hearing impairment in the medical examination, compared with 116 who reported no symptoms or only slight impairment.

Non-complainers with hearing abnormalities: Abnormal audiograms were identified in 42% of divers and 45% of offshore workers who reported no symptoms in the questionnaire survey. This finding was anticipated and is well recognised, since the early signs of noise induced hearing loss identified on audiograms are entirely asymptomatic. This supports the use of audiograms in screening populations at work for evidence of noise induced injury.

4.3.6 Diving Experience

Information on diving experience was collected by several methods in this study; postal questionnaire (questionnaire survey: Part 1), an interview with a Hyperbaric doctor (clinic study: Part 2) and evaluation of diving logbooks (clinic study: Part 2). The following assessment with diving logbooks is based on the whole sample of divers from Part 2 (n=233).

4.3.7 Professional diving logbooks

Divers were asked to bring to the clinic study a full set of diving logbooks covering the duration of their professional diving career. Only 27% of divers (n=63) produced a full set of logbooks and the reliability analysis was conducted on only these divers. A further 52% had an incomplete set of logbooks and 21% were unable to find or bring in any logbooks.

Divers with a full set of logbooks were younger (mean (95%CI): 43 (41-45) *vs.* 46 (45-47) years, p=0.001), had shorter diving careers (15 (14-16) *vs.* 18 (17-19) years, p<0.001) and started their diving career later (1977 *vs.* 1982, p<0.001). There was no difference, however, in the proportion of forgetful divers (28%) and non-forgetful divers (27%) with a full set of logbooks. Comparing different industries, police divers were most likely to have a full set of diving records and shellfish divers least likely to have a complete set.

4.3.8 Comparison of complete sets of logbook data with interview data

Divers recalled accurately the year of their first (correlation: r=0.98) and last professional dive (correlation: r= 0.94).

Diving Techniques: Table 21 shows the correlations between the interview recall and logbook entries for different diving techniques. Data is present for only those who reported to have used the specific diving techniques. A greater number of dives were recalled in the interview than documented in the logbooks for all diving techniques, except air/nitrox surface demand diving. The correlations were highest for saturation diving.

***Depth of diving*:** Divers were asked in the interview to state the percent of their dives that fell into each depth category used in the questionnaire survey. The agreement, based on correlations, was high for air/nitrox diving and saturation dives (r>0.68), with the exception of air/nitrox dives >50msw (r=0.35), but poor for mix gas bounce dives (r<0.25). The information from the interview was much less detailed than the logbooks, and the mixed gas bounce diving data were based on a small number of people.

Table 21 Comparison of divers recall of diving experience with logbook entries

	Interview median (IQR)	***Log books median (IQR)***	***Spearman's rho correlation***
Air / nitrox dives (no. dives):			
SCUBA (n=48)	207 (103-470)	138 (56-278)	0.52
Surface oxygen decompression (n=29)	300 (100-475)	130 (36-199)	0.59
Surface demand (n=44)	225 (51-545)	244 (40-453)	0.78
Mix gas bounce diving (n=13)	8 (3-35)	5 (2-13)	0.76
Saturation dives (n =23)			
No. of dives	30 (16-65)	26 (11-63)	0.95
Days in saturation	650 (400-1216)	549 (165-1032)	0.96

4.3.9 Comparison of questionnaire survey data with the interview data

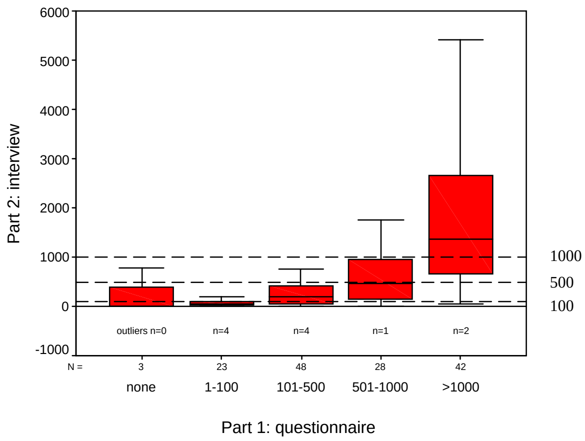
Reported duration of diving career was consistent between measures with a mean difference (95% CI) within subjects of only 1.6 (1.1-2.2) years. Obviously the difference was reduced when those divers who had dived between the two points of data collection were excluded. The only other difference was seen for those who had dived in the military (mean difference: 3.4 years (2.0-4.8)), indicating that not all divers included their military diving experience in the questionnaire survey.

***Diving techniques*:** The graphs in Figure 6 illustrate the range of diving experience reported in the interview (Part 2) with that reported in the questionnaire survey (Part 1). In general, the range of experience reported in the interview was consistent with the amount of diving reported in the questionnaire. Again, divers most consistently reported the number of days they had spent in saturation. Excluding divers (41% of random sample) who had continued to dive professionally between Part 1 and 2 of the study did not greatly alter the level of agreement already observed.

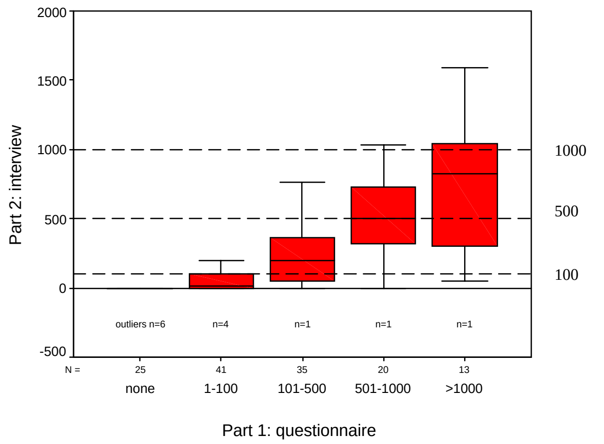
Diving related accidents: Diving related accidents were consistently reported between the questionnaire survey and the interview in Part 2. The most consistently reported accidents were neurological DCI (kappa=0.78) and pain only DCI (kappa=0.66) and the less consistently reported was exposure to contaminated gas (kappa=0.33). Exposure to contaminated gas tended to be over reported in the questionnaire survey compared with the interview in the clinic study.

4.3.10 3-day lost time accidents at work

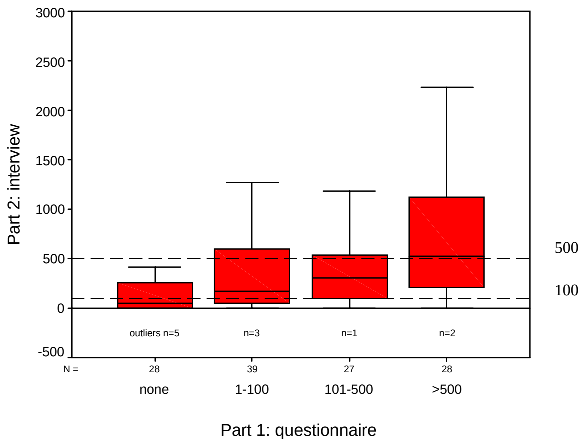
Both divers and offshore workers were more likely to report having suffered a 3-day lost time accidents in Part 2 than in Part 1 of the study. Thirty nine percent of divers and 21% of offshore workers who did not reported a 3-day lost time accident in Part 1 reported one or more at the interview (Part 2).



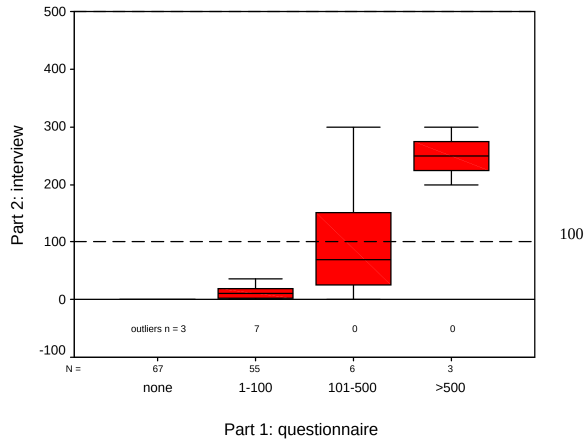
SCUBA dives

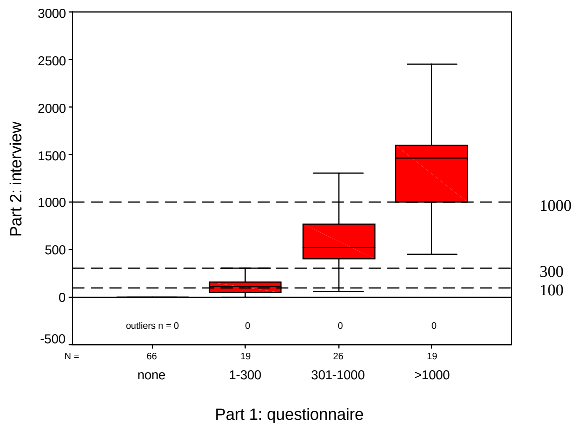


Surface oxygen decompression dives



‘Other’ air/nitrox dives (surface demand)





Days in Saturation

Figure 6 Comparison of dives reported in the interview (Part 2) and the Questionnaire survey (Part 1)

4.4 PHASE 1B: COMPARISON OF A RANDOM SAMPLE OF DIVERS & OFFSHORE WORKERS

The second objective of phase 1b was to compare characteristics of a random sample of divers and offshore workers, using objective measurements. The sample consisted of the same subjects recruited for the first part of phase 1b (n=254).

4.4.1 Neuropsychological differences

Subjects with a significant head injury (LOC ≥1hr or unknown) were excluded from the following analysis, providing a sample of 237. Divers and offshore workers did not differ in premorbid IQ, the number of years of education or measures of depression or anxiety (HADS).

Subjective neuropsychological assessments: The results shown in Table 22, illustrate that divers report more problems of memory (PRMQ) and cognitive failure (CFQ), but not executive dysfunction (DEX) than offshore workers. These results were confirmed in a multivariate analysis of variance (MANOVA) assessing the three measurements together and adjusting for covariates (see Methods) (p=0.006). Although this result was significant, only 5% of the variance in the subjective neuropsychological measurements was accounted for by group (diver/offshore worker).

Table 22 Subjective neuropsychological questionnaire results for divers and offshore workers in phase 1b

	Divers		***Offshore workers***	
	n	***mean (95% CI)***	***n***	***mean (95% CI)***
Prospective Retrospective Memory Q’	142	42.67 (41.10-44.24)	94	38.72 (37.05-40.40)
Cognitive Failure Questionnaire	138	39.54 (37.32-41.77)	95	34.57 (32.34-36.80)
Dysexecutive Function Questionnaire	141	20.99 (19.13-22.84)	94	18.26 (16.6-19.91)

Objective neuropsychological assessments: In a MANOVA considering all the objective neuropsychological assessments together (Table 23), the multivariate effect of group was found to be significant (p=0.005), explaining 12% of the variance. Overall performance was superior, although modestly, in divers compared to offshore workers. Post-hoc analysis, however, did not show any significant group differences for individual neuropsychological tests, thereby underlining the fact that any differences between the groups were modest (see Table 23). This means that the relationship between objective neuropsychological test scores was different in the divers than the offshore workers, suggesting minor variation in neuropsychological performance between the groups. The number of divers (26%) and offshore workers (17%) who failed the extradimensional shift stage of the IDED test of executive function did not differ significantly (p=0.10).

To investigate the relationship between neuropsychological performance and dive history, two composite measures of cognitive function were used (memory and executive function). The memory composite consisted of Logical Memory (immediate and delayed), CVLT (immediate and delayed) and SRM (CANTAB). The executive function composite consisted of the CANTAB measurements 5CRT, RVP, SOC and SWM. Each composite was equally weighted. Partial correlations, controlling for age, premorbid ability (NART) and head injury, revealed a small but significant relationship between memory functioning and the number of mixed gas bounce dives (r= -0.22, p=0.013), surface decompression dives (r= -0.20, p=0.026), surface demand dives r= -0.21, p=0.020) and total number of dives (r= -0.22, p=0.015); there was no significant relationship with the number of days in saturation or the amount of SCUBA diving. Further adjusting for DCI did not alter the significance of these relationships, with the exception of surface decompression diving, which failed to reach statistical significance at the 5% level (r= -0.18, p=0.052). There were no statistically significant relationships found between diving and the executive function composite score.

Table 23 Objective neuropsychological test results for divers and offshore workers in phase 1b

	Divers		***Offshore workers***	
	n	***mean (95% CI)***	***n***	***mean (95% CI)***
Logical Memory				
immediate recall	138	44.69 (43.17-46.21)	93	45.29 (43.50-47.08)
delayed recall	138	28.30 (27.16-29.45)	93	27.51 (26.13-28.88)
CVLT				
immediate recall	138	51.51 (49.85-53.18)	94	50.45 (48.19-52.70)
delayed recall	138	11.83 (11.34-12.32)	94	11.09 (10.41-11.76)
CANTAB:				
5 CRT (log10)	142	2.53 (2.52-2.54)	95	2.53 (2.51-2.54)
RVP (a' arcsin)	140	2.55 (2.52-2.58)	93	2.58 (2.55-2.62)
SRM (% arcsin)	142	2.32 (2.27-2.38)	95	2.28 (2.22-2.34)
SWM	142	24.7 (21.6-27.8)	95	23.4 (19.9-26.8)
SOC	142	9.11 (8.85-9.38)	95	8.96 (8.55-9.37)
Current IQ				
WASI vocab. T score	137	58.99 (57.96-60.02)	93	57.43 (55.80-59.06)
WASI matrix T score	141	58.26 (57.23-59.29)	95	57.89 (56.36-59.43)
WASI FSIQ	137	115.28 (113.75-116.81)	93	113.73 (111.42-116.04)

4.4.2 Medical examination

The neurological and locomotor examinations did not reveal any significant differences between the divers and offshore workers in the random sample. A similar proportion of divers (27%) and offshore workers (30%) at the time of the examination were found to be hypertensive (defined as diastolic blood pressure of 90mmHg or more).

Medical complaints: The majority of both divers (87%) and offshore workers (82%) reported a medical complaint. The reported complaints covered a wide range of conditions and therefore for the purpose of this study were coded according to the International Classification of Diseases (ICD-9) (see Appendix 3 for examples of medical conditions coded according to the ICD-9). Table 24 shows the prevalence of diseases. A greater number of divers than offshore workers reported medical complaints associated with disease of the nervous system and sense organs (p=0.007), which included hearing impairment, and disease of the skin & subcutaneous tissue (p=0.03). No other differences between divers and offshore workers were found to be statistically significant. Disease of the musculoskeletal system and connective tissue includes fractures.

An indication of the severity of medical complaints and reported symptoms was taken from information collected on the progression, impact on daily activity and treatment of each complaint or symptom reported. The worst complaint was selected individually for duration, limitation of daily activity, progression and treatment. Comparison of the worst complaint reported by divers and offshore workers did not show a difference in the severity of complaint between the two groups.

Table 24 Medical complaints (ICD-9) reported by divers and offshore workers

ICD-9 codes	***Divers (n=150)*** *n (%)*	***Offshore workers (n=103)*** *n (%)*
1. Infectious & parasitic diseases	7 (5%)	5 (5%)
2. Neoplasm	2 (1%)	1 (1%)
3. Endocrine, nutritional/metabolic diseases & immunity disorder	9 (6%)	8 (8%)
4. Disease of the blood & blood-forming organs	0 (0%)	1 (1%)
5. Mental disorder	10 (7%)	5 (5%)
6. Disease of the nervous system & sense organs	30 (20%)	8 (8%)**
7. Disease of the circulatory system	16 (11%)	13 (13%)
8. Disease of the respiratory system	14 (9%)	13 (13%)
9. Disease of the digestive system	7 (5%)	6 (6%)
10. Disease of the genitourinary system	2 (1%)	3 (3%)
12. Disease of the skin & subcutaneous tissue	24 (16%)	7 (7%)*
13. Disease of the musculoskeletal system & connective tissue	57 (38%)	40 (39%)
14. Congenital anomalies	1 (1%)	0 (0%)
15. Certain conditions originating in perinatal period	0 (0%)	0 (0%)

** $p<0.01$, * $p<0.05$

4.4.3 Audiometry

Fifty seven percent of divers compared with 50% of offshore workers had impaired hearing, the majority of which was noise induced hearing loss (Table 25).

Table 25 Divers and offshore workers with noise induced hearing loss (NIHL)

	Divers *(n=151)* ***n (%)***	***Offshore workers*** *(n=103)* ***n (%)***	*Chi-square test (group)*
LEFT ear			
Normal	58 (38%)	42 (41%)	p=0.2
Mild NIHL	23 (15%)	19 (18%)	
Moderate NIHL	24 (16%)	16 (16%)	
Severe NIHL	17 (11%)	3 (3%)	
Other hearing loss (not NIHL)	27 (18%)	21 (20%)	
RIGHT ear			
Normal	72 (48%)	51 (50%)	p=0.8
Mild NIHL	16 (11%)	14 (14%)	
Moderate NIHL	21 (14%)	10 (10%)	
Severe NIHL	11 (7%)	7 (7%)	
Other hearing loss (not NIHL)	29 (19%)	19 (19%)	
Noise induced hearing loss			
No evidence of NIHL	74 (49%)	55 (53%)	p=0.7
Unilateral NIHL	38 (25%)	21 (20%)	
Bilateral NIHL	37 (25%)	25 (24%)	
General Hearing			
Normal	63 (42%)	50 (49%)	p=0.2
Abnormal	86 (57%)	50 (50%)	

Divers were more likely to self-report having suffered one or more of the following ear complaint (87% *vs.* 48%, p<0.001): pain in their ears, an abscess, ear infections, an ear injury or perforated eardrum, or tinnitus.

There was no relationship between having previously had an ear complaint and abnormal hearing. At the time of the audiometry test a similar proportion of divers (30%) and offshore workers (24%) reported experiencing difficulty with their hearing. This was consistent with the lack of difference found with the objective audiometry measurements. It would suggest that the ear injuries and infections more commonly occur in divers but they do not have a long-term impact on their hearing.

4.4.4 Lung Function

There was little difference in the lung function of divers and offshore workers (Table 26). Since the lung function of smokers is known to be poorer than non-smokers the analysis was adjusting for smoking status. The only difference found between divers and offshore workers were in the lower range of the force expiratory flow (FEF25%, FEF50%), for which divers had lower values. Residual values (distance from the norm) produced the same results.

There was no relationship between the total number of dives performed or the different types of diving techniques used and any of the lung function tests. Furthermore, there was no difference in lung function between current and ex-divers.

Table 26 Percent predicted values for lung function tests (adjusted for height and age)

	Diver (n=151) mean (95% CI)	***Offshore workers*** (n=102) mean (95% CI)	*Unadjusted for smoking* *p-value*	*Adjusted for smoking* *p-value*
PEF	110.8 (108.6-112.9)	108.6 (105.4-111.9)	0.26	0.86
FVC	103.3 (101.2-105.4)	100.4 (97.6-103.1)	0.09	0.20
FEV_1	94.8 (92.7-96.8)	94.5 (91.6-97.4)	0.89	0.77
FVC/FEV_1	94.6 (93.3-96.0)	97.0 (95.2-98.7)	0.04	0.11
FEF25%	75.1 (71.5-78.8)	81.7 (76.3-87.2)	0.04	<0.01
FEF50%	72.6 (69.3-75.9)	78.6 (73.9-83.3)	0.03	<0.01
TLCO	93.8 (91.8-95.7)	92.7 (90.2-95.3)	0.51	0.49
KCO	105.6 (103.2-108.1)	107.3 (103.8-110.9)	0.43	0.79
TLC	97.9 (96.1-99.7)	95.2 (92.9-97.6)	0.07	0.37
RV	98.1 (94.8-101.3)	97.8 (93.6-102.0)	0.91	0.99
RV/TLC	96.1 (92.6-99.5)	97.2 (93.3-101.0)	0.67	0.48

4.4.5 Stabilometry

The results of the stabilometry tests did not show any difference in postural sway between divers and offshore workers, except for standing on soft pads (eyes closed) (Table 27).

Table 27 Postural sway of divers and offshore workers

	Divers *Mean (95% CI)*	***Offshore workers*** *Mean (95% CI)*	***t-test***
No pads			
Eyes open	12.1 (11.6-12.7)	12.4 (11.6-13.2)	p=0.6
Eyes closed	19.8 (18.6-21.0)	20.1 (18.5-21.6)	p=0.8
Head right	13.7 (13.0-14.5)	14.2 (13.2-15.2)	p=0.5
Head left	15.1 (14.3-15.9)	14.6 (13.6-15.5)	p=0.4
Head back	13.6 (12.8-14.5)	13.7 (12.8-14.6)	p=1.0
Head forward	16.1 (15.2-17.1)	16.2 (15.1-17.3)	p=1.0
Standing on soft pads			
Eyes open	15.5 (14.8-16.3)	16.1 (15.2-17.0)	p=0.4
Eyes closed	28.1 (26.6-29.6)	30.6 (28.6-32.6)	p=0.04

Note: A higher score indicates poorer postural control

4.4.6 Health Related Quality of Life

Health related quality of life (HRQOL) scores measured by the SF-36 for divers and offshore workers are shown in Table 28. There was no difference between divers and offshore workers in HRQOL scores, after adjustments were made for lifestyle factors (age, smoking, binge drinking) and head injury. The mean scores for these two groups were of the same magnitude as the mean scores from a population of men (aged 45-49 years) living in the UK from the Oxford Healthy Life Survey 1991/2 (63).

Table 28 Health related quality of life in divers and offshore workers (SF-36)

	Divers (n = 142) mean (SD)	***Offshore workers (n=95) mean (SD)***	***popn. norm* mean (SD)***
Physical Function	89.9 (17.7)	89.0 (14.8)	88.2 (18.3)
Role Limitation - Physical Problems	85.2 (31.5)	83.4 (31.5)	87.5 (28.7)
Role Limitation - Emotional Problems	87.6 (29.0)	90.9 (23.0)	86.0 (29.6)
Social functioning	90.8 (19.7)	93.0 (12.7)	89.5 (18.8)
Mental Health	78.0 (17.1)	79.2 (14.1)	75.9 (17.0)
Energy / Vitality	66.5 (19.4)	67.9 (15.7)	63.4 (20.3)
Pain	78.3 (23.0)	79.5 (21.5)	82.1 (22.8)
Health Perception	77.1 (19.9)	73.3 (18.2)	73.2 (20.1)

* Oxford Healthy Life Survey 1991/2- mean aged 45-49 years (HSRU, Oxford) (63)

4.4.7 Occupational History

The mean (95% CI) duration of the divers' careers was 17.3 (16.0-18.6) years, with a maximum of 43 years, compared with 17.2 (15.9-18.4) years that offshore workers had worked offshore (maximum of 30 years). 72% of offshore workers were still working offshore at the time they participated in Part 2 of the study compared with only 47% of divers who were actively working as divers.

Exposures: Fewer divers than offshore workers reported to have been exposed to solvents, hydrogen sulphide and noise, but divers were more likely to have been exposed to biological hazards such as sewage.

Accidents

3-day lost time accidents: A higher proportion of divers (63%) than offshore workers (40%) reported a 3-day lost time accident at work ($p<0.001$). The number of accidents per person ranged from 1 to 25 for divers (median =1) and 1 to 6 for offshore workers (median =1). The diver reporting 25 accidents had repeated ear infections preventing him from working. For 63% of the divers one or more of their lost time accidents occurred while diving.

Minor accidents: The same proportion of divers (6%) and offshore workers (4%) reported to have suffered a minor injury at work in the past year, defined as 3 or less days off work.

4.4.8 Diving History

The diving experience of the random sample, based on information from the interview with the Hyperbaric doctor is shown in Table 29. The median values presented in Table 29 are based only on those who have used the diving technique. The dives described only include 'wet' dives, since only a small minority of the sample population (6%) had done more than a few dry dives (e.g. maximum 175 chamber dives). The different industries in which divers have worked are shown in Figure 7. Many of the divers had worked in more than one of these industries. 19% of the divers had also been involved in experimental diving trials.

Table 29 Diving experience and DCI of the divers in the random sample (phase 1b)

	Used the technique	*Based on divers having used diving technique*	
Diving techniques used	***n (%)***	***Median (IQR)***	***Range***
Air/nitrox dives:			
SCUBA dives	134 (91%)	380 (115 - 1000)	3 – 13435*
Surface decompression dives	93 (65%)	250 (58 - 500)	2 - 4695
Surface demand dives	123 (84%)	300 (80 - 875)	2 - 4980
Mixed gas dives:			
Mixed gas bounce dives	61 (41%)	12 (5 - 45)	1 - 500
Saturation - dives	64 (43%)	22 (10 - 60)	1 - 150
- days	64 (43%)	500 (168 - 1090)	4 - 2450

* One diver had done 13453 short coastal civil engineering SCUBA dives

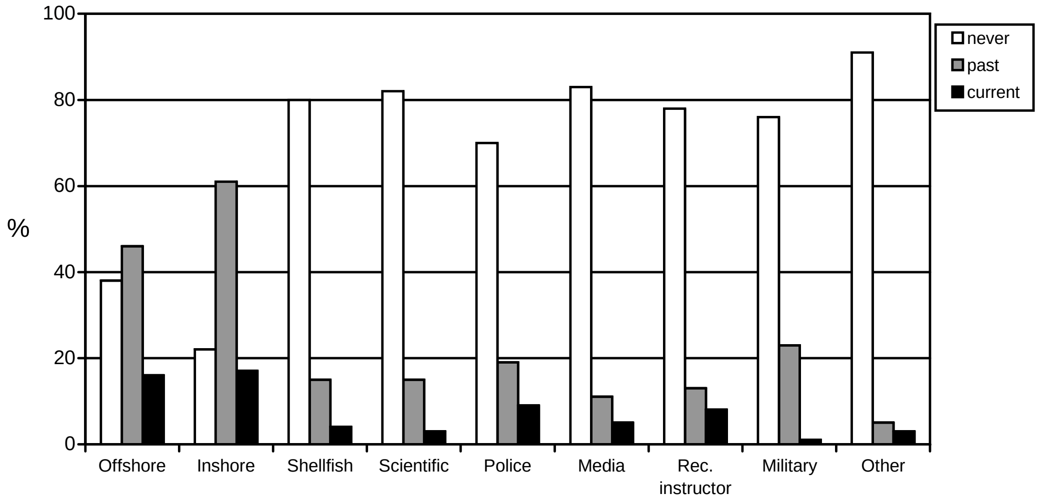


Figure 7 Industries in which divers have dived professionally

Decompression illness: Thirty percent of divers reported suffering pain only DCI and 12% of the random sample of divers reported suffering neurological DCI. Seven percent had suffered both neurological and pain only DCI.

4.4.9 ALAPS (Armstrong Laboratories Aviation Personality Survey)

The ALAPS showed that divers are more likely than offshore workers to be risk takers and impulsive but less likely to be organised (Table 30). Divers and offshore workers did not differ on scores of deference, dogmatism and team orientation. Data for a normative population for this questionnaire is not available, but scores exist for US Air Force trainee personnel (64). Divers and offshore workers scores were of a similar magnitude, except for risk taking which was higher in the Air Force personnel.

Table 30 Personality characteristics of divers and offshore workers (ALAPS)

	Divers *mean (95% CI)*	***Offshore worker*** *mean (95% CI)*	t-test	Trainee US Air Force personnel mean (SD)
Risk taking	9.8 (9.3-10.4)	7.1 (6.4-7.7)	p = <0.001	12.2 (2.9)
Impulsively	8.6 (7.9-9.3)	6.7 (6.0-7.4)	p = <0.001	7.3 (3.6)
Organisation	11.4 (10.9-11.9)	12.6 (12.0-13.2)	p = 0.002	12.4 (3.4)
Dogmatism	6.0 (5.6-6.4)	5.6 (5.2-6.1)	p = 0.2	6.0 (3.0)
Team orientation	10.8 (10.2-11.5)	11.5 (10.8-12.2)	p = 0.2	11.9 (3.8)
Deference	5.8 (5.2-6.3)	5.8 (5.1-6.4)	p = 1.0	6.3 (2.8)

4.5 PHASE 2 - CASE-CONTROL STUDY: COMPLAINT OF 'FORGETFULNESS OR LOSS OF CONCENTRATION'

Results from the questionnaire survey found that divers were significantly more likely to complain of memory and concentration problems than offshore workers when assessed by a single question (18% *vs*. 6%). This was the largest effect to emerge from the self reported symptoms, thus merited further investigation through detailed subjective and objective neuropsychological assessments. The objective neuropsychological assessment was particularly important since divers may over report loss of memory and concentration when presented with the opportunity to do so, given their enhanced awareness of possible links between diving and forgetfulness. The purpose of the case-control study was to establish whether there is a relationship between diving, forgetfulness and brain lesions.

4.5.1 Subjects

302 subjects participated in the case-control study, evenly distributed between cases and the 2 control groups. There were 7 subjects who did not report a head injury in Part 1 but in the medical examination reported a significant head injury (LOC≥ 1 hour). These 7 subjects were distributed evenly across the case and control groups and subsequently excluded from the neuropsychological and MRI analysis. A number of other subjects did not have an MRI for a variety of reasons, including having a metal implant in the face, detached retina, suffering from claustrophobia, being too large to fit in the scanner and on small number of occasions the MRI was unavailable (Table 31).

Table 31 Number of subjects included in the case-control study

Groups	***Neuropsychological tests***	***MRI scan***
CASE:		
Forgetful divers (F divers)	99	95
CONTROLS:		
Not forgetful divers (NF divers)	97	97
Not forgetful offshore workers (NF OSW)	94	89

Divers recruited for the case-control study: Both F divers and NF divers recruited for the case-control study were representative of the subgroups in the questionnaire survey from which they were recruited. Table 32 shows the diving exposure and prevalence of the main characteristics associated with reported 'forgetfulness or loss of concentration' within each of these groups. The prevalence of smoking and binge drinking were also very similar between the groups in the questionnaire survey and the case-control groups.

Table 32 Characteristics of divers recruited for the case-control study (phase 2) compared with the total sample from the questionnaire survey (phase 1a)

		F divers (n=274) phase 1a	*F divers (n=102) phase 2*	*NF divers (n=1227) phase 1a*	*NF divers (n=100) phase 2*
Age	mean (95% CI)	44.6 (43.7-45.4)	44.9 (43.5-46.3)	45.5 (45.0-45.9)	45.3 (43.7-46.9)
Welder (%)		35	30	21	16
3-day lost time accident (%)					
None		43	45	54	59
One		23	22	24	23
More than one		32	32	21	17
Head injury (%)*		23	0	15	0
Duration of diving career (yrs)					
	mean (95% CI)	16.1 (15.3-16.8)	16.4 (15.3-17.5)	14.5 (14.1-15.0)	14.7 (13.1-16.3)
SCUBA dives (%)					
None		7	8	6	3
1-100		17	17	18	15
101-500		31	22	30	38
501-1000		17	15	19	19
>1000		27	38	26	25
Surface decompression dives (%)					
None		12	16	25	30
1-100		22	20	31	30
101-500		32	29	24	22
501-1000		25	25	13	12
>1000		9	10	6	6
Other air/nitrox dives (%)					
None		28	28	39	40
1-100		29	28	23	30
101-500		25	24	20	17
>500		18	20	17	13
Mixed gas bounce dives (%)					
None		42	45	61	65
1-100		44	45	32	31
101-500		10	7	5	4
>500		3	3	1	0
Saturation - days (%)					
None		40	41	61	68
1-300		19	27	17	11
301-1000		27	22	13	12
>1000		13	10	9	9
Pain only DCI (%)					
Never		53	58	70	78
Once		21	22	15	16
More than once		24	21	14	6
Neurological DCI (%)					
Never		75	77	87	92
Once		12	13	7	4
More than once		6	6	2	1

* selected in phase 2 to exclude divers reporting a head injury

4.5.2 Lifestyle characteristics

The F divers did not differ from either control group (NF divers and NF OSW) in age, alcohol consumption (including binge drinking), smoking habits, scores of anxiety and depression or premorbid IQ. Years of education differed between the groups (p=0.02), with F divers reporting fewer years of education than NF OSW but not differing from NF divers.

3-day lost time accidents: Both F divers (64%) and NF divers (59%) were more likely than NF OSW (39%) to have had one or more 3-day lost time accidents (p=0.002). There was, however, no difference between F divers and NF divers. Thirty seven percent of F divers who reported a 3-day lost time accident had experienced more than one accident, compared to 33% of NF divers and 19% NF OSW.

4.5.3 Medical examination

The proportions of people presenting with a neurological or locomotor abnormality did not differ between the case or control groups.

Medical complaints: There was no difference found between the F divers and the control groups in the proportion of people reporting medical complaints, classified according to the ICD-9 (Table 33).

Table 33 Medical complaints (ICD-9) reported by case and control groups

ICD-9 codes	*F-divers (n=102) %*	*NF-divers (n=99) %*	*NF-OSW (n=100) %*
1. Infectious & parasitic diseases	3	4	6
2. Neoplasm	1	1	0
3. Endocrine, nutritional/metabolic diseases & immunity disorder	3	6	6
4. Disease of the blood & blood-forming organs	0	0	1
5. Mental disorder	10	7	5
6. Disease of the nervous system & sense organs	14	19	10
7. Disease of the circulatory system	7	11	13
8. Disease of the respiratory system	19	10	13
9. Disease of the digestive system	12	3	7
10. Disease of the genitourinary system	2	1	4
12. Disease of the skin & subcutaneous tissue	15	15	9
13. Disease of the musculoskeletal system & connective tissue	45	33	36
14. Congenital anomalies	0	1	0
15. Certain conditions originating in perinatal period	0	0	0

Of those subjects who reported a medical complaint, F divers were more likely than the control groups to report that the progression of their complaint was getting worse and they were more likely to be taking non-prescribed medication. It was, however, no more likely to limit daily activity.

Hypertension: More F divers (43%) were classified as hypertensive (defined as a diastolic blood pressure measurement of 90mmHg or more, or previously diagnosed) than NF divers (30%) and NF OSW (32%), based on the blood pressure measurement taken in the medical examination (chi-square: p=0.12). Table 34 shows details of mean blood pressure in the case and control groups in both normotensive and hypertensive subjects.

Table 34 Blood pressure of normotensive and hypertensive subjects in the case and control groups

	Normotensive subjects			***Hypertensive subjects****		
	F diver (n=58)	***NF diver (n=69)***	***NF OSW (n=68)***	***F diver (n=44)***	***NF diver (n=30)***	***NF OSW (n=32)***
Diastolic blood pressure (mmHg) mean (95% CI)	79 (77-81)	78 (76-80)	78 (76-79)	96 (92-99)	96 (93-99)	95 (92-98)
Systolic blood pressure (mmHg) mean (95% CI)	141 (137-145)	142 (138-146)	142 (138-146)	164 (159-170)	164 (158-169)	166 (158-173)

*diastolic blood pressure ≥ 90mmHg or previously diagnosed

Consistency of reported forgetfulness: F divers were selected on the basis of self-reporting of forgetfulness or loss of concentration in the questionnaire survey (Part 1). During the medical examination they were again asked if they suffered from forgetfulness or loss of concentration. 98% of NF offshore workers and 92% of NF divers reported consistently with Part 1 that they did not to suffer from forgetfulness or loss of concentration, but only 43% of F divers reported in the medical examination that they suffered from forgetfulness of loss of concentration.

The consistent and inconsistent reporters in the F divers group did not differ in age, education, alcohol consumption or smoking habits. Divers consistently reporting forgetfulness had higher scores for both depression and anxiety assessed using the HADS than those inconsistently reporting. The consistent reporters scored higher on all the subjective neuropsychological measures, but did not differ significantly on objective neuropsychological test results.

4.5.4 Neuropsychological Assessments

Subjective neuropsychological assessments

Analysing the questionnaires in a single analysis (MANOVA) revealed a significant effect of group ($p<0.001$). F divers scored higher than both control groups on all of the questionnaires, demonstrating a higher level of self-reported memory problems and cognitive failure (Table 35). This effect remained significant after adjusting for covariates (premorbid IQ, age, years of education, alcohol consumption (units per year), smoking (pack years), and anxiety and depression).

Table 35 Subjective neuropsychological assessments for case and control groups

	F Diver (n=99) mean (95% CI)	***NF diver (n =97)*** mean (95% CI)	***NF OSW (n=94)*** mean (95% CI)
PRMQ	49.0 (47.3-50.7)	40.3 (38.7-41.9)	37.4 (35.7-39.0)
CFQ	48.1 (45.3-50.9)	36.5 (34.1-38.9)	33.0 (30.8-35.1)
DEX	24.5 (21.9-27.2)	18.9 (17.1-20.7)	17.5 (15.9-19.1)

Objective neuropsychological assessments

As described previously, due to the high correlation among the objective neuropsychological tests, these data were analysed together in a single model (MANOVA). An overall difference was found for the neuropsychological tests between the groups for both unadjusted ($p<0.001$) and adjusted data ($p=0.003$) (Table 36). More specifically, F divers performed significantly worse than NF divers on the measures of LM immediate recall, LM delayed recall, CVLT immediate recall, CVLT delayed recall and verbal intelligence (WASI). F divers performed significantly worse than NF offshore workers on measures of LM immediate recall, LM delayed recall and RVP. The pass and fail rates for IDED stage 8 (extradimensional set shifting) did not show a significant difference between the case and control groups ($p=0.2$) (Table 37). Thus there was significant evidence of a decline in performance in divers reporting loss of memory and concentration in both memory and attention measures when compared with the control groups. WASI full scale IQ (current IQ) was significantly lower in the F divers but this difference was reduced to a non-significant level after the covariates were controlled for in the model.

Table 36 Neuropsychological test results for the case - control groups

	F Diver mean (95% CI)	***NF Diver*** mean (95% CI)	***NF OSW*** mean (95% CI)	***Unadjusted (n=277)***	***% variance explained****	***Adjusted (n=262)*****	***% variance explained****
Logical Memory							
Immediate recall	40.7 (39.0-42.3)	45.3 (43.5-47.2)	45.0 (43.0-46.9)	p<0.001	6%	p = 0.007	4%
Delayed recall	24.0 (22.7-25.4)	29.2 (27.8-30.5)	27.8 (26.4-29.1)	p<0.001	10%	p<0.001	8%
CVLT							
Immediate recall	48.2 (46.3-50.1)	52.4 (50.4-54.5)	50.7 (48.4-53.1)	p = 0.02	3%	p = 0.03	3%
Delayed recall	10.5 (9.8-11.1)	12.1 (11.5-12.7)	11.2 (10.4-11.9)	p = 0.002	5%	p = 0.002	5%
CANTAB:							
5 CRT (log 10)	2.54 (2.53-2.55)	2.52 (2.51-2.53)	2.53 (2.52-2.54)	p = 0.12	2%	p = 0.27	1%
RVP (arcsin)	2.52 (2.49-2.55)	2.58 (2.54-2.61)	2.60 (2.56-2.63)	p = 0.005	4%	p = 0.02	3%
SRM (arcsin)	2.27 (2.22-2.33)	2.37 (2.31-2.43)	2.32 (2.26-2.38)	p = 0.09	2%	p = 0.09	2%
SOC	8.8 (8.5-9.2)	9.0 (8.7-9.3)	9.1 (8.7-9.5)	p = 0.53	1%	p = 0.74	0.02%
SWM	24.1 (20.1-27.1)	23.8 (20.2-27.5)	21.2 (17.9-24.5)	p = 0.23	1%	p = 0.67	0.03%
Current IQ:							
WASI FSIQ	111.4 (109.2-113.5)	116.0 (114.5-117.5)	113.6 (111.0-116.2)	p = 0.01	3%	p = 0.08	2%
WASI vocab	55.8 (54.2-57.4)	59.3 (58.1-60.5)	57.1 (55.2-59.0)	p = 0.007	4%	p = 0.05	2%
WASI matrix	56.7 (55.2-58.1)	58.7 (57.7-59.7)	58.0 (56.4-59.7)	p = 0.17	1%	p = 0.48	1%

* variance in neurological test explained by group (case and controls)

** adjusted for: estimated premorbid IQ (NART), age, years of education, alcohol units per year, pack years, anxiety and depression.

Table 37 Pass and fail rates for IED stage 8 (extradimensional set shift)

	Pass	*Fail*
F diver (n=99)	74 (75%)	25 (25%)
NF diver (n=97)	72 (74%)	25 (26%)
NF OSW (n=94)	79 (84%)	15 (16%)

ABNORMALITIES: The incidence of frank abnormality (>1.65 SD below population mean) on measures with significant effects for the case and control groups shows that, with the exception of the RVP in F divers, the percentage of divers classified as exhibiting an abnormality was well below the expected value of 5% (Table 38).

Table 38 Abnormality incidence rates for the tests that differed between the case-control groups

	LM immediate (n=282)	*LM delayed (n=282)*	*CVLT immediate (n=282)*	*CVLT delayed (n=282)*	*RVP (n=286)*
F divers	3 (3.1%)	1 (1.1%)	1 (1.0%)	1 (1.0%)	8 (8.1%)
NF divers	1 (1.1%)	0 (0%)	1 (1.1%)	1 (1.1%)	3 (3.2%)
NF OSW	1 (1.1%)	1 (1.0%)	2 (2.2%)	3 (3.3%)	2 (2.2%)

4.5.5 MRI Assessment

Very few subjects in the study (less than 3%) had grey matter hyperintensities in different regions of the brain. Analysis of the incidence of grey matter hyperintensities between groups was therefore not possible due to these small numbers.

White matter abnormalities

Results from the detailed scale composed for this study showed that, if subcortical and deep white matter hyperintensities (WMH) were present, they tended to be located in the frontal lobes (approximately 57% of the whole sample had hyperintensities in this region). In total 60% of subjects had WMH (3% had hyperintensities located in regions other than the frontal lobes) and 76% had periventricular hyperintensities (PVH). Given the limited extent of hyperintensities in regions other than the frontal lobes, group differences were assessed for simply the presence or absence of WMH and PVH. In addition, given the presence of neuropsychological group differences in memory and attention scores, groups were also assessed for differences in incidence of hyperintensities (yes/no) in functionally relevant brain areas, the parietal (attention) and temporal (memory) lobes. Table 39 shows the prevalence of white matter abnormalities in F divers, NF divers and NF OSW.

Table 39 Prevalence of MRI detected white matter abnormalities for the case-control groups

	Prevalence of white matter abnormalities (n (%))		
	F diver ***(n=95)***	***NF diver*** ***(n=97)***	***NF OSW*** ***(n=88)***
All white matter abnormalities (WMH and/or PVH)	86 (91%)	80 (83%)	73 (83%)
White matter hyperintensities (WMH)	57 (60%)	65 (67%)	47 (53%)
Periventricular hyperintensities (PVH)	78 (82%)	67 (69%)	67 (76%)
Anatomical Regions			
Temporal lobe WMH	13 (14%)	13 (13%)	9 (10%)
Parietal lobe WMH	21 (22%)	27 (28%)	23 (26%)
Frontal lobe WMH	53 (56%)	60 (62%)	46 (52%)
Occipital lobe WMH	4 (4%)	2 (2%)	3 (3%)

WMH = subcortical and deep white matter hyperintensities.

Table 40 shows the relationship of white matter abnormalities with diving and reports of 'forgetfulness or loss of concentration'. Divers are more likely than offshore workers to have white matter hyperintensities, but this is not related to 'forgetfulness or loss of concentration'. Periventricular hyperintensities, however, are more common among subjects reporting to suffer from 'forgetfulness or loss of concentration', which in this sample are F divers. There was no difference in the prevalence of periventricular hyperintensities between divers and offshore workers.

Adjusting the divers' MRI data for decompression illness (pain only or neurological) did not alter the relationships observed in Table 40.

Table 40 MRI detected white matter abnormalities related to diving and reported 'forgetfulness or loss of concentration'

		Unadjusted ***Odds ratio (95% CI)***	***p***	***Adjusted ****** ***Odds ratio (95% CI)***	***p***
All white matter abnormalities (WMH and/or PVH)	Diver*	0.96 (0.45-2.06)	0.91	0.92 (0.41-2.06)	0.83
	Forgetful**	2.11 (0.89-5.02)	0.09	2.05 (0.83-5.07)	0.12
White matter hyperintensities (WMH)	Diver	1.82 (1.00-3.32)	0.05	1.92 (1.00-3.67)	0.05
	Forgetful	0.81 (0.45-1.47)	0.48	0.70 (0.37-1.33)	0.28
Periventricular hyperintensities (PVH)	Diver	0.72 (0.37-1.40)	0.34	0.67 (0.34-1.32)	0.24
	Forgetful	2.05 (1.04-4.07)	0.04	2.17 (1.07-4.43)	0.03

* likelihood of divers compared with OSWs having an abnormality, ** likelihood of subjects reporting to suffer from 'forgetfulness or loss of concentration' having an abnormality, *** analysis adjusted for age, hypertension, alcohol consumption and smoking

Hypertension and MRI hyperintensities: Hypertensive subjects (diagnosed hypertension or measured diastolic blood pressure ≥90mmHg) (76%) were more likely than normotensive subjects (51%) to have subcortical and deep WMH ($p<0.001$), but the difference in the prevalence of PVH between hypertensive subjects (81%) and normotensive subjects (72%) failed to reach statistical significance at the 5% level ($p=0.09$). Table 41 illustrates the prevalence of white matter abnormalities in normotensive and hypertensive subjects in the case and control groups. The percent of hypertensive subjects with subcortical and deep WMH was significantly higher than in normotensive subjects for both F divers ($p=0.02$) and NF OSW ($p<0.001$), but not NF divers ($p=0.3$) where the percentage did not alter. There was no significant difference, in any of the groups, between the percent of normotensive and hypertensive subjects with PVH.

Normotensive divers (both F and NF) were more likely than normotensive OSW (NF) to have subcortical and deep WML, but this was not related to forgetfulness ($p=0.02$).

Table 41 MRI detected white matter abnormalities for normotensive and hypertensive subjects in the case-control groups

	Normotensive subjects			***Hypertensive subjects****		
	F diver (n=56)	***NF diver (n=68)***	***NF OSW (n=58)***	***F diver (n=39)***	***NF diver (n=28)***	***NF OSW (n=30)***
All white matter abnormalities (WMH and/or PVH)	48 (86%)	55 (81%)	44 (76%)	38 (97%)	24 (86%)	29 (97%)
White matter hyperintensities (WMH)	28 (50%)	43 (63%)	23 (39%)	29 (74%)	21 (75%)	24 (80%)
Periventricular hyperintensities (PVH)	45 (80%)	46 (68%)	41 (71%)	33 (85%)	20 (71%)	26 (87%)

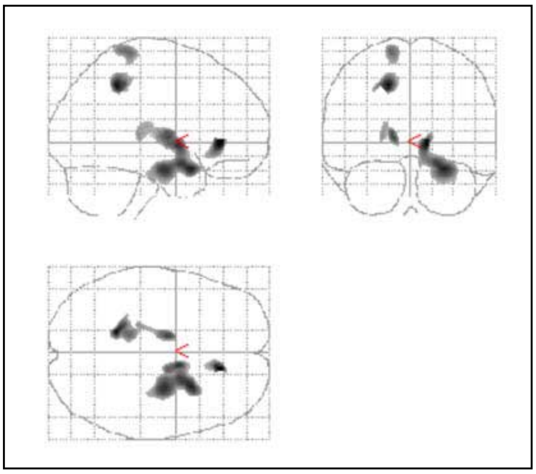
* diastolic blood pressure ≥ 90mmHg or diagnosed

HRQOL and MRI hyperintensities: Health related quality of life (SF-36), after adjustment lifestyle factors, did not show a relationship with PVH or WMH.

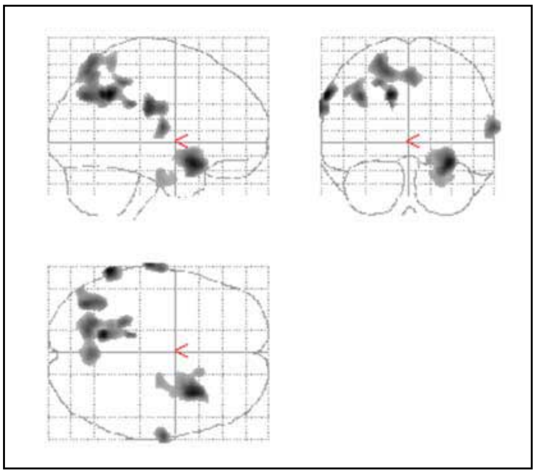
Volumetric analysis

T1 weighted MRI data was analysed using Voxel Based Morphometry (VBM), as described in in the methodology. The resulting t-statistics were thresholded at $p=0.01$ (uncorrected) for display, and maxima at $p<0.005$ (uncorrected) are reported. No significant differences in regional grey matter volume were found between NF OSW and NF divers. However, significant regional grey matter reductions were found in F divers compared to NF OSW, and also in F divers compared to NF divers (Figure 8). The regions highlighted in these images represent the area where grey matter reductions occur in the brains of F-divers.

The most significant differences in grey matter volume are found in the left parietal and right inferior frontal regions, with differences also present in the right temporal region when comparing F divers to NF divers. A review of the function significance of the left parietal and inferior frontal regions has shown that they are involved in verbal and numeric working memory and spatial episodic memory (65). The right temporal region has been shown to be activated when performing dual working memory tasks. Reduced grey matter volume in areas found to be involved in working memory tasks may result in reduced functional capacity in these areas. These are preliminary volumetric results based on standard methods of analysis and therefore should not be considered as a definitive description of volume changes in divers. There has not been enough time within this study to conduct this analysis allowing for possible confounding variables, such as age and hypertension, as has been done for the analysis of white matter abnormalities.



F divers compared to NF OSW



F divers compared to NF divers

Figure 8 Glass brain diagrams for regional grey matter reductions in F divers compared with NF OSW and NF divers (at the p<0.005 threshold)

4.5.6 Health related quality of life (SF-36)

Overall the groups differed in HRQOL, as analysed by MANOVA (p<0.001, explaining 8% of the variance) and remained significantly different after adjusting for lifestyle factors (p<0.001, explaining 8% of variance) (Table 42). Further analysis showed that F divers had lower HRQOL than both of the control groups, scoring significantly lower on all components of the SF36. The only exception to this was with role limitation (physical and mental) where the F divers did not differ from the NF OSW. The NF divers did not differ from the NF OSW.

Furthermore, adjusting HRQOL for neuropsychological test results reduced the effect of group (p=0.03). All individual HRQOL factors remained statistically significant, suggesting that memory and cognitive problems do not fully explain the difference in HRQOL between the case and control groups.

Table 42 SF-36 HRQOL of the case and control groups

	F diver (n=99) mean (SD)	*NF diver (n=97)*	*NF OSW (n=94)*	*Unadjusted comparison (n=290)*	*Adjusted comparison (n=267)**	*popn. norm* (63)
Physical Function	82.8 (23.9)	93.3 (10.7)	90.5 (13.7)	p<0.001	p<0.001	*88.2 (18.3)*
Role Limit Physical	78.3 (36.0)	90.7 (22.6)	84.6 (30.7)	p=0.02	p=0.05	*87.5 (28.7)*
Role Limit Mental	81.5 (32.7)	92.8 (22.2)	91.1 (23.0)	p=0.006	p=0.02	*86.0 (29.6)*
Social Functioning	82.9 (25.6)	94.6 (11.8)	93.0 (12.8)	p<0.001	p<0.001	*89.5 (18.8)*
Mental Health	72.1 (19.9)	80.5 (13.5)	79.2 (14.2)	p=0.001	p=0.004	*75.9 (17.0)*
Energy/Vitality	57.7 (22.5)	69.5 (15.0)	68.4 (16.6)	p<0.001	p<0.001	*63.4 (20.3)*
Bodily Pain	69.0 (25.2)	82.8 (17.6)	82.2 (19.5)	p<0.001	p<0.001	*82.1 (22.8)*
Health Perception	67.2 (22.5)	80.6 (15.2)	74.2 (18.8)	p<0.001	p<0.001	*73.2 (20.1)*

* analysis adjusted for age, alcohol units per year and pack years

In order to estimate the significance of the HRQOL scores the effect size (d) was calculated between F divers and NF divers. The effect size for each of the different aspects of the SF-36 was ‘moderate’, ranging from 0.40 to 0.66 (Table 43). These values were similar to those observed for diagnosed medical conditions in the questionnaire survey for the SF-12 (see Table 12).

Table 43 Effect size for the difference in SF-36 scores between NF divers and F divers

SF-36	*Effect size (d) between NF divers (n=97) and F divers (n=99)*
Physical Function	0.55
Role Limit Physical	0.41
Role Limit Mental	0.40
Social Functioning	0.56
Mental Health	0.48
Energy/Vitality	0.59
Bodily Pain	0.61
Health Perception	0.66
SF-12 (PCS)	0.53
SF-12 (MCS)	0.49

Note: d = NF divers (mean score) - F diver (mean score) / pooled SD

4.5.7 Diving experience of forgetful and non-forgetful divers

The duration of diving careers of F divers and NF divers was not significantly different but F divers had done significantly more professional dives than NF divers (p=0.03) (Table 44). Figure 9 illustrates the frequency distribution of F divers and NF divers for the total number of professional dives. The majority of dives reported by the NF diver who had done 13707 professional dives were short coastal civil engineering SCUBA dives. F divers began their diving career slightly earlier than NF divers (1978 *vs.* 1980). The same proportion of F divers (47%) and NF divers (48%) were still working as professional divers at the time of the study.

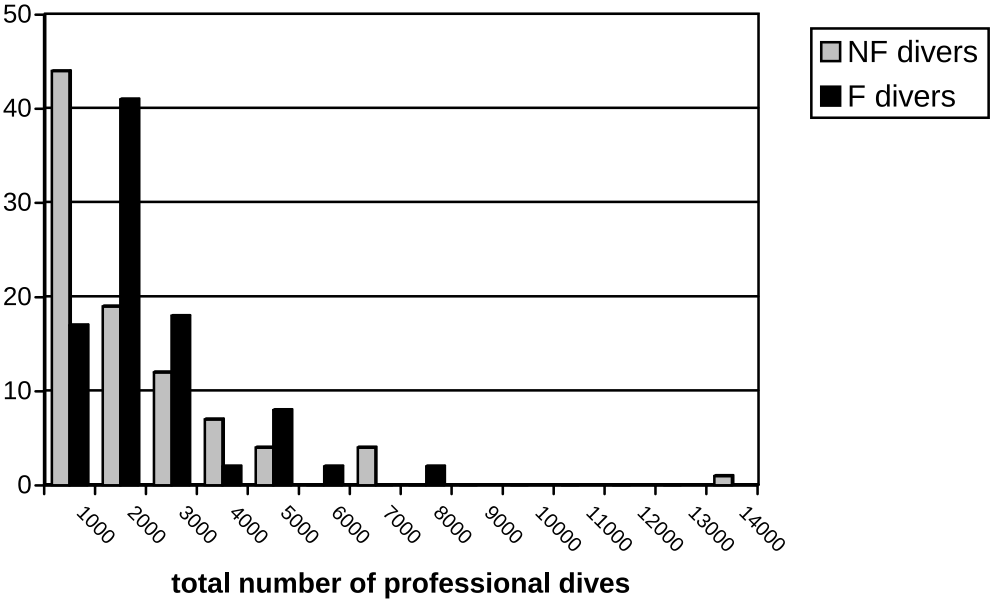


Figure 9 Frequency distribution of the total number of professional dives performed by F divers and NF divers

Diving techniques: A significantly higher proportion of F divers than NF divers had done surface decompression diving (p<0.001), mixed gas bounce diving (p=0.002) and saturation diving (p<0.001), but there was no difference for SCUBA (p=0.3) or surface demand diving (p=0.3) (Table 44). Of those who had used these techniques, F divers and NF divers had done a similar number of dives.

Table 44 Diving experience of F divers and NF divers

	F divers (n=99)		***NF divers (n=97)***		
Years professionally dived mean (95% CI)	18.0 (16.7-19.3)		16.5 (14.8-18.2)		p=0.16
Total number of dives median (IQR)	1610 (1099-2512)		1033 (485-2547)		p=0.03
	Used this technique	***No. dives /days*** *median (IQR)*	***Used this technique***	***No. dives/days*** *median (IQR)*	***Mann Whitney****
Scuba dives	86%	500 (129-1000)	92%	350 (100-975)	p=0.29
Surface demand dives	86%	460 (100-871)	82%	260 (60-691)	p=0.11
Surface decompression dives	80%	275 (100-513)	51%	285 (83-526)	p=0.78
Mixed gas bounce dives	53%	12 (6-50)	30%	12 (4-30)	p=0.45
Saturation diving:	58%		31%		
dives		20 (7-40)		20 (12-63)	p=0.52
days		450 (127-1323)		430 (165-885)	p=0.64

* comparison of number of dives/days

***Depth of dives*:** F divers tended to have dived, using air/nitrox, to a greater maximum depth than NF divers (mean (95% CI): 56.0 (52.5-59.5) *vs.* 51.1 (48.1-54.1) p=0.04). There was, however, no difference between these two groups for the maximum depth of mixed gas bounce dives and saturation dives.

Diving industries: The majority of divers had dived in more than one industry during their career. A significantly higher proportion of F divers (73%) than NF divers (55%) had worked as a diver in the offshore industry (p=0.008). NF divers were more likely than F divers to have dived in the police force (p=0.03), media (p=0.005), as a recreational instructor (p=0.04) or as a scientific diver (p=0.06).

Decompression illness: F divers (47%) were more likely to have suffered DCI than NF divers (21%) (p<0.001). Thirty six percent of F divers compared with 18% of NF divers had suffered pain only DCI (p=0.003). Twenty two percent of F divers and only 4% of NF divers had suffered neurological DCI (p<0.001).

4.5.8 Relationship of diving history with objective neuropsychological performance

To investigate the relationship between neuropsychological performance and dive history, the two composite measures of cognitive function were used (memory and executive function), as described in section 4.4.1. Partial correlations, controlling for age and premorbid ability (NART), revealed a small but significant relationship between memory functioning and the number of mixed gas bounce dives (r= -0.19, p=0.016); there was no significant relationship with the amount of other diving techniques used. Linear regression analysis confirmed this observation.

There was no difference in composite scores in those people with a history of DCI, as compared to those people who had not. Also, there was no difference in those people with a specific history of neurological DCI as compared to all others in the two groups, including those with pain only DCI.

In this sample of divers, the memory composite score provided additional confirmation that the point at which the original question, about the complaint of ‘forgetfulness or loss of concentration’, had been dichotomised for the case-control study was appropriate. Figure 10 illustrates the split between ‘non-forgetful’ divers (‘not at all’ or ‘slightly’) and ‘forgetful’ divers (‘moderately’ or ‘extremely’). A score of zero represents the average composite score for this sample of divers (as indicated on the graph). The majority of ‘non-forgetful’ divers had scores above zero, indicating an above average memory score, while the majority of ‘forgetful’ divers had scores lower than zero, indicating a lower than average memory score within this sample. F divers had memory composite scores significantly lower than NF divers (p<0.001), but there was no difference between those reporting the complaint ‘not at all’ and ‘slightly’. Similarly the memory composite score did not differ significantly between those reporting to suffer ‘moderately’ and ‘extremely’. The executive function composite score, however, did not relate to reported severity of ‘forgetfulness or loss of concentrations’ among divers (p=0.9).

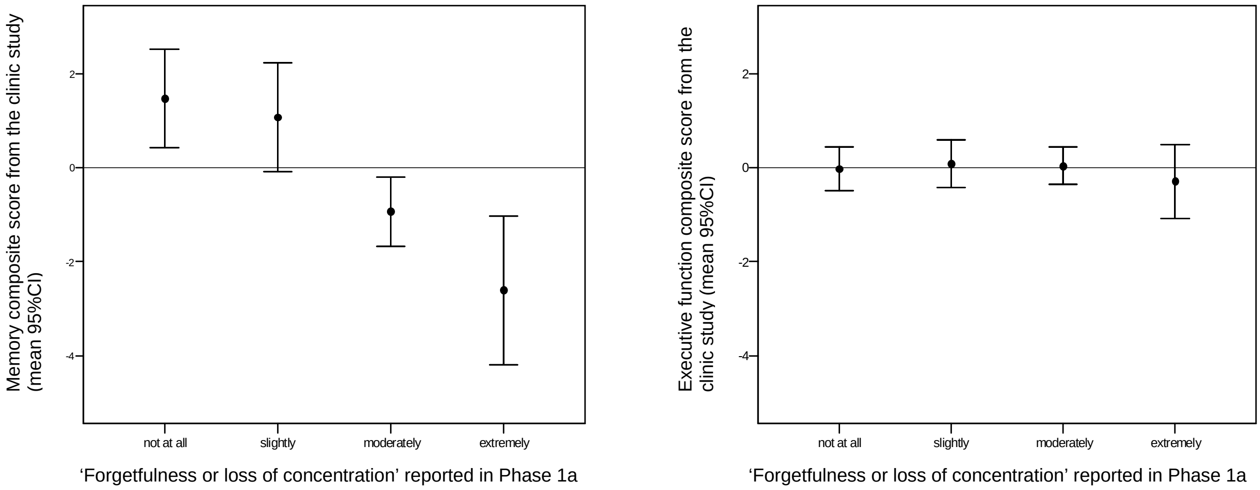


Figure 10 Memory and executive function composite scores in the different categories 'forgetfulness or loss of concentration' reported in phase 1a (questionnaire survey) by divers in the case-control study

4.5.9 Relationship of diving history with MRI hyperintensities

Comparisons showed that only mixed gas bounce diving was significantly associated with MRI hyperintensities and specifically to WMH and not PVH (Table 45). After adjusting for age and hypertension, WMH and frontal lobe hyperintensities remained significantly related to mixed gas bounce diving, but temporal lobe hyperintensities (p=0.06) and parietal hyperintensities (p=0.08) failed to reach statistical significance at the 5% level. There were no significant relationships found between any of the MRI measures and surface decompression diving, SCUBA diving, surface demand diving or the total days in saturation.

Table 45 Prevalence of MRI hyperintensities with diving confounders

	Pain only DCI		***Neurological DCI***		***Mixed gas bounce diving***	
	No (n=141)	Yes (n=50)	No (n=167)	Yes (n=24)	No (n=113)	Yes (n=78)
Subcortical & deep WMH	90 (64%)	31 (62%)	107 (64%)	14 (58%)	63 (56%)	58 (74%)**
PVH	108 (77%)	37 (74%)	127 (76%)	18 (75%)	83 (74%)	61 (78%)
Frontal lobe WMH	81 (57%)	31 (62%)	99 (59%)	13 (54%)	58 (51%)	54 (69%)*
Temporal lobe WMH	16 (11%)	10 (20%)	25 (15%)	1 (4%) #	10 (9%)	16 (21%)*
Parietal lobe WMH	37 (26%)	11 (22%)	42 (25%)	6 (25%)	22 (20%)	26 (33%)*

*p<0.05, **p<0.01, # Analysis not valid: sample size was too small

4.5.10 ALAPS

The results from the ALAPS are shown in Table 46. Both F divers and NF divers were more likely than NF OSW to be impulsive and risk takers, but F divers were less organised than NF divers and NF OSW.

Table 46 ALAPS scores for the case and control groups

	F divers (n=99) *mean (95% CI)*	***NF divers (n=97)*** *mean (95% CI)*	***NF OSW (n=94)*** *mean (95% CI)*	ANOVA
Dogmatism	5.9 (5.4-6.4)	5.7 (5.2-6.2)	5.6 (5.1-6.1)	p=0.7
Deference	6.4 (5.8-7.0)	5.6 (5.0-6.3)	6.2 (5.5-6.9)	p=0.2
Team orientation	11.0 (10.2-11.7)	11.5 (10.8-12.3)	11.3 (10.5-12.0)	p=0.6
Organisation	10.3 (9.7-10.9)[1]	12.6 (11.6-12.7)[2]	12.4 (11.8-13.0)[2]	p<0.001
Impulsivity	9.0 (8.3-9.8)[1]	7.9 (7.0-8.7)[1]	6.5 (5.8-7.3)[2]	p<0.001
Risk taking	10.0 (9.3-10.6)[1]	9.1 (8.5-9.8)[1]	6.7 (6.0-7.4)[2]	p<0.001

[1] is significantly different from [2] (p<0.001)

4.5.11 Stabilometry

There was no difference between the case and control groups in the measurement of postural sway (Table 47).

Table 47 Postural sway measured in case and control groups

	F divers (n=99) *mean (95% CI)*	***NF divers (n=97)*** *mean (95% CI)*	***NF OSW (n=94)*** *mean (95% CI)*	ANOVA
No pads				
Eyes open	12.7 (11.9-13.5)	11.7 (11.3-12.2)	12.2 (11.3-13.0)	p=0.1
Eyes closed	19.4 (17.9-20.9)	19.1 (17.7-20.4)	19.5 (17.8-21.1)	p=0.9
Head right	13.6 (12.8-14.3)	13.3 (12.5-14.2)	13.5 (12.7-14.3)	p=0.9
Head left	14.1 (13.3-15.0)	14.7 (13.7-15.6)	14.3 (13.4-15.2)	p=0.7
Head back	13.3 (12.3-14.4)	13.1 (12.3-13.9)	13.2 (12.2-14.1)	p=0.9
Head forward	15.7 (14.7-16.8)	15.7 (14.6-16.8)	15.4 (14.2-16.5)	p=0.9
Soft pads				
Eyes open	15.0 (14.0-16.0)	14.9 (14.2-15.6)	15.7 (14.8-16.5)	p=0.4
Eyes closed	28.1 (26.2-30.1)	27.0 (25.5-28.4)	29.4 (27.4-31.3)	p=0.2

Note: A higher score indicates poorer postural control

5 DISCUSSION

5.1 BACKGROUND

The long term health effects of diving have been authoritatively reviewed on three occasions in the past 10 years: at an International Consensus Conference (1983) in Godesund (55); by Elliott and Moon in the same year (66); and again in 2003 (67). The Consensus Statement from the Godesund Conference stated (p.391):

"There is evidence that changes in bone, the central nervous system and the lung can be demonstrated in some divers who have not experienced a diving accident or other established environmental hazard.

The changes are in most cases minor and do not influence the diver's quality of life. However, the changes are of a nature that might influence the diver's future health"

Moon and Elliott (66), in the same year, concluded (p.600): "In the absence of such a precipitating event, (decompression illness) only deafness and osteonecrosis have been recognised as clinical entities. ……………Therefore in the absence of a history of acute decompression illness, the possibility of a clinical syndrome among divers or ex-divers remains unproven."

Recently the effect of diving on the lung, bones and nervous system were separately reviewed. Osteonecrosis was recognised as a problem for divers and compressed air workers with the major additional risk factors of obesity and alcoholism (68). Review of the literature on pulmonary effects identified studies published since the Godesund conference that supported its conclusions but although long term effects on the lung had been seen, there was no indication of a health impact (69). A longitudinal study carried out after this review confirmed changes induced by diving on small airway function but provided no indication of an effect on health. Review of central nervous system effects accepted long term spinal cord and cerebral injury after decompression illness as identifiable entities but also concluded "There is no credible evidence that a DCS event sets into motion a progressive deterioration of intellect." The case for brain injury after diving without a history of decompression illness was also reviewed concluding: "Many workers have described minor symptoms in many divers, but no one has shown significant or progressive disability that interferes with activities of daily living" (70).

Much has been said in these reviews regarding the health impact of diving but there is a dearth of research into the subject of the overall health of divers and we identified no studies where health related quality of life has been formally assessed. None of the papers reviewed identifying a difference between divers and controls in any aspect of physical or mental function has related it to a quality of life measure.

The only systematic assessments of general health amongst divers were conducted by the American military. A review of 197 divers identified obesity and decrements of high and low tone perception on audiometry (71) but without comparison with a control group. A later study on 11,517 navy divers indicated that divers had significantly higher hospitalisation rates between the ages of 23-28 for environmentally induced disorders, deflected nasal septum and joint disorders (72). From the age of 41 there were no differences between divers and a control population. The absence of similar studies on non-military professional divers is important since the experience of military divers is limited compared to an average commercial diver. Also, there are indications in the literature that military divers may differ from sport or commercial divers. For instance, groups of military divers did not show the retinal or cerebral MRI changes previously identified in sport or commercial divers (26;31).

There was a need, therefore, for a large general health survey of commercial divers.

In this study we explored self-reported health and health related quality of life in a large group of divers compared to a non-diving group of offshore industrial workers by means of a questionnaire survey. We then validated the questionnaire responses by a detailed clinic assessment of a random sample from each group. That assessment included a range of objective tests and measurements. Finally we explored factors associated with reported symptoms in a case-control study, to determine the significance of these symptoms and the contribution of diving and diving practices to these symptoms.

5.2 COMPARISON OF THE DIVER AND OFFSHORE WORKER STUDY POPULATIONS

The questionnaire study gathered information on lifestyle and demography. Fewer divers were current smokers and divers also had smoked less overall. Divers were less likely to binge drink but the frequency of consuming more than 80 or more than 160 units per month was the same. The level of alcohol consumption at doses known to affect health was therefore considered to be similar in the two groups.

An indicator of deprivation, the Carstairs Score, showed that both groups tended to higher affluence than the general population. Divers showed significantly different educational attainment as assessed by qualifications. Fewer divers attained HNC/HND and University degree level but more attained O' level qualifications but the differences are small and do not take account of professional training attainment. Hence it is unclear, from these data alone, whether there was any difference in intellectual ability between the groups. Diver training has been equated with an O' level educational attainment (12) and, if this were accepted, it would further blur the differences between the two groups. The clinic Study data support a lack of difference in intellectual ability between groups in this study since a measure of premorbid intelligence, the National Adult Reading Test, showed no between group differences either in the random sample or in the case control study.

Demographically, therefore, with the exception of smoking habit, the two groups were remarkably similar.

There were significant differences in general work related factors between the groups. Twenty-three percent of divers had worked as a welder compared to 5% of offshore workers. There was also a higher report of 3 day lost time accidents in the diver group; 47% as against 29% in offshore workers. This may have been an underestimate in reporting since the figures from the occupational history taken at the clinic study were 63% and 40% respectively. Further, the prevalence of a diving accident history was high (Table 5) and, in addition, 94% of welders had suffered a welding accident at some stage. Overall work related accidents appear more common in diving than in topside offshore work.

In the Questionnaire study there were differences in medically diagnosed conditions. After adjustment for lifestyle factors, divers were less likely to have suffered cerebral strokes than offshore workers and this is likely to be related to the lower prevalence of diagnosed hypertension in divers. There were also fewer asthmatics among the divers as a result of their health assessment requirements.

In the questionnaire study there were differences in reported symptoms. More divers reported 'forgetfulness and loss of concentration', 'joint pain or muscle stiffness' or 'impaired hearing' after adjustment for lifestyle factors. This study investigated whether these complaints were associated with diving or with other work related factors. In the whole study population there were significant relationships between these complaints and reports of head injury, 3 day lost time accident and experience as a welder. When these factors were allowed for, only the complaint of 'forgetfulness or loss of concentration' remained independently associated with diving although there were indications that musculoskeletal and hearing symptoms may be associated with specific diving practices.

5.3 HEALTH RELATED QUALITY OF LIFE IN DIVERS AND OFFSHORE WORKERS

We have used the measurement tools SF-12 in the questionnaire study and SF-36 in the clinic study to compare health related quality of life (HRQOL) between groups. We also explored within the groups factors that were associated with changes in HRQOL. Although HRQOL scores were similar when divers and offshore workers were compared as groups, factors associated with reduction in HRQOL differed between the groups. In the questionnaire survey there was a lower score for the mental component of HRQOL in offshore workers but this was not lower than the expected population norm and the effect size (0.1) was below that considered significant. Further, once adjustment was made for lifestyle factors the significance of this particular difference was lost, indicating that it did not relate to work activities. This conclusion was supported by data from the clinic study using the SF-36 administered to a random sample of the questionnaire population.

Across all subjects the major work related factor associated with reduction in HRQOL was industrial accident whether or not it was associated with diving. Such accidents were more frequent in the diving group. The question arose, therefore, of whether HRQOL would have been higher in divers were it not for these events.

Among divers, some association of accidents with reduction in HRQOL was attributable to diving accidents since, when these were allowed for, accidents were no longer associated with reduction in the mental component of HRQOL in divers. This conclusion is supported by the significance of diving accidents in a linear regression model (Table 14). Furthermore, the reduction in HRQOL related to accidents was less in divers and this was supported in the linear regression model by significant positive interaction between lost time accidents and being a diver. This might indicate that the accidents divers suffered were less serious than those sustained by offshore workers. However, in the clinic study, there was no indication at interview that non-diving accidents were any less severe in divers than in offshore workers. It might be that either divers are more robust in this respect or are less likely to suffer social consequences such as job loss.

Unexpectedly, having worked as a welder was also associated with a reduced physical component of health related quality of life and this is discussed further below.

From our analysis, it was clear that the report of symptoms was an associate of HRQOL. When those symptoms that differed between the two groups were added to the linear regression much more of the variance in the model was explained. This is not surprising for the complaint of 'joint pain and muscle stiffness' since pain is the subject of specific enquiry in the SF-12 and a degree of correlation was anticipated. Also HRQOL is known to be reduced in an occupational setting in association with musculoskeletal symptoms (73). The SF-12, however, makes no specific cognitive or hearing enquiry.

When all the factors associated with reduction in HRQOL were allowed for, there remained no difference between offshore workers and divers. This suggests that neither did divers start off with a higher HRQOL nor were they more disadvantaged by work related factors overall than offshore workers.

This analysis did indicate, however, that within the two groups studied, health related quality of life was affected by factors that differed between the two groups. The most notable areas of difference were in subjective complaint of ‘joint pain or muscle stiffness’, ‘impaired hearing’ and ‘forgetfulness or loss of concentration’.

In order to estimate the significance of changes in HRQOL associated with these symptoms we analysed effect size (57). We demonstrated an effect size, which indicated that the impact of these symptoms was comparable to diagnosed medical conditions. Similar effect size was observed in the clinic study using the SF-36. The effect sizes reported in this study were greater than in other studies using the same methodology such as those in British (74) and American (75) soldiers after the First Persian Gulf War and in occupational groups (76). The impact on HRQOL associated with these symptoms is therefore important and merits further clarification.

5.4 COMPLAINT OF ‘IMPAIRED HEARING’

Hearing symptoms were more common in divers (16% *vs.* 11%) but this difference was explained by allowance for the greater prevalence of accident history and work as a welder in the diving group. Despite this, and the absence of a relationship with diving overall, there was a significant dose response relationship between symptoms and saturation diving (Table 9) in the questionnaire study. In the clinic Study, more divers than offshore workers complained of poor hearing (30% *vs.* 24%), a similar relative difference to that seen in the questionnaire study, but not statistically significant due to the smaller sample size. Subjective hearing complaint, however, grossly underestimated objectively identified hearing loss and, accordingly, differences in complaint are of limited significance. Further, the frequency of ear infection amongst saturation divers might lead them to a greater perception of hearing problems. Audiometric assessment in the clinic Study showed no difference in the prevalence of hearing disorder identified and, specifically, no difference in the incidence of noise induced hearing loss. There was no relationship between diving experience and hearing loss identified on audiometry.

Other workers have identified increased rates of hearing impairment in divers in comparison with population norms (50) and more rapid deterioration of hearing with age (51) and it has been suggested that ear injury due to diving might explain this. Our data indicate that ear injury is not associated with undue hearing loss in divers nor is there any association with a history of decompression illness. The prevalence of objectively observed hearing loss is high, however, but similar to an equivalent industrial population and the prevalence of noise induced hearing loss is the same. Currently, an audiogram is part of both the divers’ and offshore workers’ medical examination and our data support this practice, although raises questions about whether abnormal findings are acted upon to prevent progressive hearing loss. Given the high rates of hearing disorder identified in this study, a project examining the results of these examinations and the actions that flow from them would seem appropriate.

5.5 COMPLAINT OF 'JOINT PAIN AND MUSCLE STIFFNESS'

More divers complained of 'joint pain or muscle stiffness' but the difference was lost when accidents and work as a welder were allowed for in the analysis. There was no relationship between musculoskeletal complaint and diving overall but divers that had suffered pain only decompression illness more frequently made the complaint and there were dose response relationships within the model with surface demand diving and mixed gas bounce diving. Interestingly, Hoiberg and Blood reported higher rates of joint disorders in divers aged 23-28 (72). Decompression illness can affect muscle tissue (77) and there is evidence that muscle damage occurs in gas embolism (78). In the clinic study, however, at medical interview, there was no difference between divers and offshore workers in the occurrence of musculoskeletal disease. No subjects reported a diagnosis of dysbaric bone necrosis in this study.

5.6 COMPLAINT OF 'FORGETFULNESS OR LOSS OF CONCENTRATION'

The principal finding from the questionnaire study was the increased frequency of a report of 'forgetfulness or loss of concentration' amongst divers (18%) compared to offshore workers (6%). The difference remained after correcting for confounding factors and, accordingly, it was the subject of a case control study using neuropsychological testing and cerebral MRI.

The questionnaire study indicated that the complaint of 'forgetfulness or loss of concentration' was related to diving and was not attributable completely to other factors. There was a positive relationship between the number of years of diving experience and the degree of complaint. Also, the prevalence of complaint was higher as divers performed more saturation, mixed gas bounce or surface oxygen decompression diving. There was no such relationship with SCUBA or surface demand air diving. While these relationships persisted after allowance for confounding factors, there were other associations with the complaint. A history of 3 day lost time accident, head injury, decompression illness and work as a welder all were significant in the model used.

Accidents may cause cognitive complaint either resulting from a psychological response or from central nervous system injury with sequelae. Accident victims are known to suffer psychological sequelae (79) and psychological recovery is not as good after workplace accidents compared to those occurring elsewhere (80). Accident may also be associated with brain injury and effects on cognition. In this study, a history of head injury was associated with the complaint. Also, a history of diving accident, which may include neurological decompression illness or cerebral gas embolism, accounted for the decline in the mental component of HRQOL and a history of decompression illness accounted for the increased prevalence of the complaint associated with surface oxygen decompression diving.

There is also some evidence that people with subjective cognitive complaint are more accident prone than those without (81) and it has been suggested that cognitive impairment can lead to an increased risk of accident rather than the accident itself causing the complaint.

In the case control study divers complaining of 'forgetfulness or loss of concentration' had poorer performance both in subjective and objective neuropsychological testing, particularly of memory. However, we did not identify any cases of frank abnormality associated with the complaint. Neither was there an unexpected incidence of neuropsychological abnormality in subjects who had no symptoms. Hence subjects with a perception of having a poor memory performed less well on tests of memory function than subjects without such a perception but without any indication of abnormality.

Composite scores were used to assess possible influencing factors on neuropsychological test performance of memory. In the random sample, there was a weak but significant correlation with the total number of dives in a career but no indication that a history of decompression illness was important. There were also weak but significant negative correlations between memory performance and the amount of mixed gas bounce diving, surface oxygen decompression diving and surface demand diving. Although weak, the degree of correlation matched that found in previous studies in divers without a history of decompression illness (12). When a history of decompression illness was allowed for, the significance of the surface oxygen decompression diving correlation was lost. This supported the questionnaire study observation that a history of decompression illness might account for the relationship between the complaint of forgetfulness and experience of surface oxygen decompression diving. However, the correlation of complaint with mixed gas bounce diving was retained, even allowing for a history of decompression illness.

In the case control study no correlation was found between the overall number of dives performed and memory performance. However, when specific dive techniques were explored, number of mixed gas bounce dives was significantly associated with lower performance. Further, in the case group, there were significantly more divers who had dived with mixed gas bounce, surface oxygen decompression and saturation techniques. This supports the observation that prevalence of complaint was related to experience of these techniques.

From these observations it can be reasoned that both the prevalence of complaint and severity of complaint of ‘forgetfulness and concentration’ relate to diving experience. There are also indications that specific diving techniques are implicated. Memory performance is also negatively related to diving experience and is poorer in people with complaint. The relationship between diving experience and memory performance, however, was not as strong as that with complaint identified in the questionnaire study. This may simply be due to the smaller numbers in the clinic study.

The case control study also identified structural differences in the brains of divers with complaint and these are discussed below.

5.7 CEREBRAL MRI STUDIES

Cerebral MRI indicated that there were structural differences between the groups tested. Divers overall had a higher incidence of subcortical white matter hyperintensities and divers in the case group, with complaint of “forgetfulness or loss of concentration”, had more periventricular hyperintensities. The potential importance of such observations is related to their association with reduction in cognitive ability in the over 60s (82). An increased frequency of white matter hyperintensities has been previously observed in groups of divers (22;23;25;83) and one study has associated them with reduction in neuropsychological test performance (14) albeit not with memory reduction. The observation of an increase in periventicular hyperintensities has not been made before and this may be important as it these have been associated with cognitive impairment (84;85).

Raised blood pressure was an associate of subcortical white matter hyperintensities in divers and controls and this is in agreement with the current opinion that hypertension is the most important risk factor for white matter hyperintensities (86). Previous studies in divers have not made this association, but have focussed on divers in employment who, due to medical screening, would not have been hypertensive. In our study, diving was an independent risk factor. White matter hyperintensities associated with hypertension have been linked to small blood vessel damage (87) and similar damage has been implicated in post mortem studies of divers brain (33) and in animal decompression models (88). Subcortical hyperintensities were not associated with cognitive decline in this study and it is likely that it is possible to sustain a certain burden of these brain changes without a functional effect.

Periventricular hyperintensities have been associated with the rate of cognitive decline with age (89) and with a negative effect on episodic memory (85) in cross sectional studies and were more frequent in forgetful divers. They were not associated with hypertension, however, and there are indications in the literature that their aetiology may differ from that of subcortical hyperintensities (87). While subcortical hyperintensities are generally thought to be of vascular aetiology, periventricular hyperintensities may also be caused by disruption of the integrity of the ependymal layer of the ventricles resulting in leakage of cerebrospinal fluid into the tissue surrounding the ventricles (87;90). There has been no suggestion to date that diving causes such changes and this area is worth further exploration.

Further indication that the case group was structurally different was obtained from Statistical Parametric Mapping 2 (SPM). This technique assumes parametric statistical models at each voxel, using the General Linear Model to describe the variability in the data in terms of experimental and confounding effects, and residual variability. This gives an image of the brain whose voxel values are statistics (http://www.fil.ion.ucl.ac.uk/spm). Mapping the differences between the groups indicated that divers had reduced grey matter volume in areas associated with memory when compared to control divers and offshore workers. SPM has also been used to analyse HMPOA SPET brain scans in divers with decompression illness demonstrating areas of persistent hypoperfusion in the occipito-parietal-temporal regions (91). The areas affected differ from those areas of grey matter volume reduction seen with MRI in the present study. The investigation of decompression illness as an explanatory factor has not yet been possible, but since different areas of the brain are affected in DCI it might seem that DCI is less likely to be a factor. As the prevalence of decompression illness in the forgetful divers group was higher than in the control group (47% *vs*. 21%), however, this needs to be controlled for in any future analyses. A history of DCI, however, was not significant in terms of the other MRI observations of hyperintensities in this study. The SPM results are only preliminary. The data have been corrected with brain volume as a confounding factor, but have been normalised to a standard template. Further analyses using a study specific template and controlling for age are required (61).

As with the neuropsychological data in this study, the changes in white and grey matter observed did not amount to pathological change known to be typical of a disease state. The abnormalities quantified in this study can be regarded as variations of the normal spectrum. However, if they are part of a progressive phenomenon, they may become clinically significant.

Previous studies have identified many of the effects regarding cognitive function and cerebral imaging seen here. This study, however, has produced a dataset that identifies cognitive complaint and establishes its importance with regard to quality of life, and its association with diving. In the same subjects it has also proved possible to confirm the validity of the complaint at a group level using objective neuropsychological testing and to identify structural differences on cerebral MRI. The effects seen, however, do not amount to what could be termed a disease state. Nevertheless there are parallels in this population of relatively young subjects with a current concept in cognitive complaint in a more elderly population, which has loosely been termed mild cognitive impairment (MCI). MCI is a clinically deduced condition typified by a cognitive complaint, usually of memory although other domains can be affected. This is associated with impaired performance for age and education on objective tests of memory or other domains in people who have normal day to day activities and are not demented (92). MCI is a significant risk factor for future conversion to Alzheimer’s Disease in those with memory complaint, or other forms of dementia when other domains are affected (93). In our study, the case group of divers complaining of moderate to severe ‘forgetfulness or loss of concentration’ did have a memory complaint. However, formal tests of memory, although revealing lower performance than control, did not demonstrate abnormal performance for age and education. In addition, the mean age of the study group here was approximately 45 with only 10 people in the case control group being 65 or over. Whether the case group of divers represent a population at risk of faster than usual cognitive decline with age who may go on to develop MCI with its prognostic significance is a question for a longitudinal study.

5.8 WELDING

Fourteen per cent of the study population were welders and all but a few of these people were also divers. Work as a welder contributed significantly to a greater likelihood of the complaints most reported by divers, and controlling for welding experience greatly reduced the difference between divers and offshore workers.

Welding is associated with a number of well-documented hazards. The general morbidity and mortality of welders is worse than other groups of workers (94). Accordingly, welding must be taken into consideration in any approach to the long term health impact of professional diving.

History of work as a welder was found to be associated with lower physical quality of life, and increased complaint of ‘forgetfulness and loss of concentration’, ‘joint pain or muscle stiffness’ and ‘impaired hearing’. Welders were more likely to have a history of a 3 day lost time accident and 90% of the group had suffered a welding accident with 19% having had one or more major electrical shocks.

That welders might have musculoskeletal complaints is not unexpected. Welding is associated with a need to work in cramped conditions and subjective symptoms as well as clinical signs and symptoms are more common among welders than office workers (95). Symptoms affecting the neck and upper extremities in welders are also associated with sickness absence (96).

In relation to impaired hearing, the exposure of welders to noise is high (97) and use of hearing protection is not routine. Also, welders are at risk of middle ear damage due to sparks. Hearing complaint, however, is not a reliable way of assessing noise induced hearing loss. There were, however, too few welders in the clinic study to investigate this further.

The association between welding and complaint of ‘forgetfulness or loss of concentration’ was surprising. The high accident rate in this group may be important, since accidents are also associated with the complaint. Welders also may be exposed to high levels of inhaled toxins (97). Metal fumes, fumes from the flux used, nitrogen oxides, carbon monoxide are all potential hazards in welding and, for divers the inert gases used for shielding also pose a hazard due to their narcotic properties at pressure. Carbon monoxide exposure has a potential for causing both acute and chronic neurological effects and the permitted limits for CO exposure in a hyperbaric welding habitats were higher (70 ppm 8 hour TWA) than the industry norm for working at atmospheric pressure (50 ppm 8 hour TWA) although this has been remedied. A study on welders in Manitoba, in addition to identifying high levels of exposure to carbon monoxide, also documented high exposure levels to manganese and iron (97). Aluminium fume inhalation is also a potential hazard. Both manganese (98) and aluminium (99;100) exposure has been related to cognitive impairment in welders and manganese exposure also affects mood and autonomic function (101). Neuropsychiatric symptoms are more frequent in welders with prolonged exposure to lead, manganese or aluminium (102).

There may be interaction between welding and diving. In addition to exposure to welding related toxins in an enclosed and potentially poorly ventilated underwater welding habitat, the effect of a high pressure environment must be considered. For example, argon which is commonly used as an inert shielding gas, is a narcotic at high pressure. More worrying is the potential of high hydrostatic pressure to amplify the toxicity of already hazardous chemicals. In cell culture work, the toxicity of the welding-fume component chromate was amplified by hydrostatic pressure (103).

Data from the questionnaire suggest that divers who weld are more at risk of forgetfulness or loss of concentration than non-diving welders, as shown in Table 8. The effect was not due to divers having a longer welding career than non-diving welders since they actually had spent less time as welders. The incidence of such reported problems in welder divers is also some 11% higher (27%) than for non-welder divers (16%).

There are clear indications that work as a welder may be a risk factor in terms of cognitive complaint in divers and this factor needs further follow up both in terms of accurate exposure data and objective testing.

5.9 HEALTHY WORKER, SURVIVOR, SAMPLING AND RESPONSE BIAS

In designing the study it was important to avoid the problems of “healthy worker” and “survivor” bias. We chose as the entry criterion in the study registration as a diver before 1991 or fitness to work in the offshore oil industry in the years 1990-1992 and there was no requirement for subjects to be working in either of the two occupations at the time of the study. Both occupational groups are subject to a similar and obligatory medical examination and are required to meet fitness to work criteria.

The healthy worker effect is due to the comparison of a population employed in an occupation with the general public. This was avoided by comparing two populations in employment at the start of the study with similar standards of fitness to work. There were also similar rates of current employment in the two groups studied and the duration of employment in each of the industries of interest was the same.

The survivor effect is caused by unhealthy people dropping out of a workforce leaving only the healthy behind. This was avoided here by not requiring subjects to be in the occupations of interest at the time of the study. People dropping out of the occupations because of ill health would therefore have been captured.

Sampling bias was minimised by identifying a target population by reference to already established lists of suitable subjects and then age matching the groups. Nevertheless the sampling strategy used differed between the two groups. Divers qualified if they were registered to work as a diver before 1991 and offshore workers qualified if they had a fitness to work offshore medical between 1990 and 1992. This strategy may have given rise to a tendency for divers to be older or to have worked longer in the profession of interest. Age matching countered the first problem and, in fact, similar proportions of each group had been in the respective professions for longer than 15 years. The questionnaire, however, did not establish the length of offshore worker career beyond 15 years. In the clinic study, however, a 10% randomly chosen representative sample of the questionnaire subjects had an occupational history taken. This sample accurately reflected the questionnaire population in other respects and showed that mean duration of career was 17.3 years for divers and 17.2 years for offshore workers at the time of interview. Further, duration of career did not differ between people who had stopped diving or had left the offshore industry (Table 17), although divers tended to start their career earlier than offshore workers and those that had stopped diving had also done so earlier. This might well have been caused by the difference in sample selection between groups but is unlikely to introduce bias.

Of more concern was that divers stop diving at an earlier age than people leave the offshore industry (Table 17). While 72% of offshore workers were still working in the offshore industry only 47% of divers were still actively diving. Both age and occupational status can introduce bias and so health related quality of life was compared between groups allowing for these factors. The mental health component of the SF-12 questionnaire score was unaffected. The physical component, however, was lower in people that had left their respective industries and somewhat lower again in the offshore worker group. These effects, however, were due to age rather than group or occupational status and, since age had been included in our assessment of health related quality of life there would be no bias from this source.

The response rates of approximately 50% to the questionnaire study raise the possibility of bias in that those people not responding might differ from those that do. We assessed this possibility by looking for differences between the groups that responded to the first and third mailings since these latter, without a third mailing, would have been non-responders (62). The presence of trend in series of mailings has also been used to predict characteristics of non-responders (104). There were, however, no trends across the three mailings. Non-responders may be of lower educational attainment, smoke more and have less neck or back pain. The purpose of this study, however, was not to establish the true prevalence of complaint but only to identify problem areas.

5.10 CONCLUSIONS AND RECOMMENDATIONS

The main positive findings in this study were as follows.

- The major work related factor affecting health related quality of life was work related accident and this effect was most marked for offshore workers.
  - Effective accident prevention, therefore, would have major implications for the well being of this workforce.

- A significant group of divers complained of 'forgetfulness or loss of concentration' and this was related to their diving experience. This complaint was associated with a significant moderate reduction in health related quality of life. A random sample of this group had lower performance than control on objective tests of cognitive function most particularly of memory and had structural differences from control subjects on cerebral MRI. There are parallels in this group with conditions predisposing to dementia in the over 65s.
  - There should be follow-up studies in order to determine whether divers in this group are of increased risk of dementia in old age and to identify possible predisposing factors.
  - Certain diving techniques, notably mixed gas bounce diving but also saturation and surface oxygen decompression diving, were associated with the effect and these practices should now also be examined for possible causative factors.

- The practice of welding had an unexpected amplifying effect in terms of the symptoms experienced by divers. Of as much concern, there was evidence that welding of itself could be associated with cognitive complaint and further studies are required here.
  - Further work needs to done to assess the interaction between welding and diving
  - Further work is needed to study the impact of welding on cognitive function

- There was a very high prevalence of hearing disorder in a population that regularly undergoes audiometry. It may be that the employer is unaware of audiometry data from these medical examinations. Divers, however, seemed at no more risk of hearing impairment than offshore workers.
  - A system of feeding back this information to employers might prove a useful tool for monitoring work place safety in this respect.

6 APPENDICES

6.1 APPENDIX 1: QUESTIONNAIRE USED IN THE POSTAL SURVEY (PART 1)

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Environmental and Occupational Health Questionnaire

Please answer all questions (except in sections 2.1 to 2.3 where you should only answer the sections which apply to you).

Answer the questions by placing **a cross or a number** (as appropriate) in the box. If you make a mistake place a single line through the incorrect answer and put a cross in the box of the correct answer.

For example: What is your CURRENT marital status? never married [X] married [ ] divorced or widowed [ ]

All the information you provide will be STRICTLY CONFIDENTIAL

Section 1 LIFESTYLE

Date of birth D D / M M / Y Y Y Y

Male [ ] Female [ ]

What is your CURRENT marital status? never married [ ] married [ ] divorced or widowed [ ]

What is your CURRENT living situation? living alone [ ] living with friends [ ] living with a partner / family [ ]

What is the highest educational qualification you have gained?
none [ ] O' Levels, Standard Grades, School Certificate [ ] A ' Levels, Scottish Highers [ ] HNC/HND [ ] University Degree [ ]

Which of the following best describes your CURRENT work status?
employed [ ] unemployed [ ] not working & on sickness benefits or retired through ill health [ ] retired [ ]

How much do you currently weigh? [ ][ ] • [ ][ ] st. lbs **OR** [ ][ ][ ] kgs

How tall are you? [ ][ ] • [ ][ ] ft.ins **OR** [ ][ ][ ] cms

Have you smoked more than 100 cigarettes IN TOTAL in your life ? yes [ ] no [ ]

If yes, complete the following:

<u>Current smokers</u>

How many *years* in total have you smoked? [ ][ ]

How many *cigarettes* do you smoke per day? [ ][ ][ ]

<u>Ex-Smokers</u> - in what *year* did you stop smoking? [ ][ ][ ][ ]

How many *years* in total did you smoke? [ ][ ]

How many *cigarettes* did you smoke per day? [ ][ ][ ]

How often have you drunk the following alcoholic drinks in the last 12 months ?

	5-7days a week	*3-4 days a week*	*1-2 days a week*	*1-2 times a month*	*less than monthly*	*not at all*
beer, lager or cider	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
wine	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
spirits	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

During the past 12 months, how often have you drunk 8 units or more of alcohol on any one occasion?
(8 units = 4 pints of normal strength beer, lager or cider <u>OR</u> 8 small glasses of wine <u>OR</u> 8 shots of spirit)

never [ ] more than 20 times a month [ ] 10-20 times per month [ ] 1-9 times per month [ ] if LESS than monthly, how many times per year? [ ][ ]

Have you ever done recreational underwater diving? yes [ ] no [ ]

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Section 2 OCCUPATIONAL HISTORY

In the course of *your work*, have you been exposed to any of the following?

	no, not at all	*yes, a little*	*yes, a lot*		*no, not at all*	*yes, a little*	*yes, a lot*
Petrochemicals, solvents or paints	[ ]	[ ]	[ ]	Asbestos	[ ]	[ ]	[ ]
Drilling mud	[ ]	[ ]	[ ]	Hydrogen sulphide	[ ]	[ ]	[ ]
Radiation sources	[ ]	[ ]	[ ]	Rock or coal dust	[ ]	[ ]	[ ]
Noise (loud enough to make conversation difficult)	[ ]	[ ]	[ ]				

Have you had a lost time (i.e. more than 3 days) accident or injury at work? no [ ] once [ ] more than once [ ]

When was your last medical (fitness to work) examination? [ ][ ][ ][ ] year

2.1 Please complete if you have worked as an <u>OFFSHORE WORKER</u> (oil or gas industry) (if not go to section 2.2)

How many years in total have you worked offshore? less than 5yrs [ ] 5-10yrs [ ] 11-15yrs [ ] more than15yrs [ ]

2.2 Please complete if you have worked as a <u>DIVER</u> (if not go to section 2.3)

In what year was your FIRST <u>commercial</u> dive? [ ][ ][ ][ ] **and when did you LAST dive <u>commercially</u>?** [ ][ ][ ][ ]

<u>DIVING EXPERIENCE:</u> For *each* of the following types of diving, how many dives in TOTAL have you done?

Air/Nitrox Dives			Mixed Gas Bounce Dives	Saturation Dives
number of SCUBA dives	number of surface decompression dives	number of other air/nitrox dives	number of mixed gas bounce dives	total number of <u>days</u> in saturation
none [ ]	*none* [ ]	*none* [ ]	*none* [ ]	*none* [ ]
1-100 [ ]	*1-100* [ ]	*1-100* [ ]	*1-100* [ ]	*1-300* [ ]
101- 500 [ ]	*101- 500* [ ]	*101-500* [ ]	*101-500* [ ]	*301-1000* [ ]
501-1000 [ ]	*501-1000* [ ]	*more than 500* [ ]	*more than 500* [ ]	*more than 1000* [ ]
more than 1000 [ ]	*more than 1000* [ ]			

<u>DIVING DEPTH:</u> How often have you dived to *each* of the following depths (meters of sea water)?

Air/Nitrox Dives	*never*	*occasionally*	*a lot*	Mixed Gas Bounce Dives	*never*	*occasionally*	*a lot*	Saturation Dives	*never*	*occasionally*	*a lot*
less than 30	[ ]	[ ]	[ ]	*less than 80*	[ ]	[ ]	[ ]	*less than 100*	[ ]	[ ]	[ ]
30-50	[ ]	[ ]	[ ]	*80-120*	[ ]	[ ]	[ ]	*100-180*	[ ]	[ ]	[ ]
more than 50	[ ]	[ ]	[ ]	*more than 120*	[ ]	[ ]	[ ]	*more than 180*	[ ]	[ ]	[ ]

While working as a diver have you suffered from any of the following?

	never	*once*	*more than once*
Neurological decompression sickness	[ ]	[ ]	[ ]
Pain only decompression sickness	[ ]	[ ]	[ ]
Cerebral gas embolism	[ ]	[ ]	[ ]
Underwater explosion	[ ]	[ ]	[ ]
Drilling mud skin burn	[ ]	[ ]	[ ]
Loss of consciousness while under pressure	[ ]	[ ]	[ ]

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Have you ever been exposed to contaminated breathing gas? never ☐ once ☐ more than once ☐

How many **recreational** dives have you done? none ☐ 1-100 ☐ 101-500 ☐ 501-1000 ☐ more than 1000 ☐

In what year was your FIRST **recreational** dive? ☐☐☐☐ and when did you LAST dive **recreationally**? ☐☐☐☐

2.3 Please complete if you have worked as a WELDER (if not go to section 3)

How many years in total have you worked as a welder? less than 5yrs ☐ 5-10yrs ☐ 11-15yrs ☐ more than 15yrs ☐

Which of the following welding techniques have you used?

Manual Metal Arc (MMA) ☐ Metal Inert Gas (MIG) ☐ Tungsten Inert Gas (TIG) ☐

Gas (oxyacetylene) ☐ Flux Cored Arc (FCA) ☐

Which of the following materials have you handled when WELDING and / or GRINDING?

	Welding			Grinding		
	not at all	*a little*	*a lot*	*not at all*	*a little*	*a lot*
Stainless steel	☐	☐	☐	☐	☐	☐
Steel	☐	☐	☐	☐	☐	☐
Aluminium	☐	☐	☐	☐	☐	☐
Copper nickle alloy	☐	☐	☐	☐	☐	☐

While working as a welder/grinder have you suffered from the following?	*never*	*once*	*more than once*
Major electric shock	☐	☐	☐
Metal fume fever	☐	☐	☐
Burns (including radiation burns)	☐	☐	☐
Eye damage (e.g. arc eye, flash, radiation)	☐	☐	☐

Section 3 GENERAL HEALTH

Do you regularly suffer from any of the following?	*not at all*	*slightly*	*moderately*	*extremely*
Joint pain or muscle stiffness	☐	☐	☐	☐
Back pain or neck pain	☐	☐	☐	☐
Breathlessness	☐	☐	☐	☐
Cough or wheeze	☐	☐	☐	☐
Abdominal pain, diarrhoea, constipation or nausea	☐	☐	☐	☐
Muscle weakness or tremor	☐	☐	☐	☐
Unsteadiness when walking, dizziness or poor balance	☐	☐	☐	☐
Forgetfulness or loss of concentration	☐	☐	☐	☐
Impaired vision (not corrected by spectacles)	☐	☐	☐	☐
Impaired hearing	☐	☐	☐	☐
Skin rash or itch	☐	☐	☐	☐

Are you currently receiving any medical treatment or medication?

yes ☐ no ☐ if yes, please provide details: ☐

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Have you ever been diagnosed with any of the following conditions?

	yes	*no*		*yes*	*no*		*yes*	*no*
Asthma	☐	☐	High blood pressure	☐	☐	Ulcer (stomach or peptic)	☐	☐
Stroke	☐	☐	Depression or anxiety	☐	☐	Cancer (including leukaemia)	☐	☐
Dermatitis	☐	☐	Diabetes	☐	☐	Eczema or hayfever	☐	☐
Arthritis	☐	☐	Head injury	☐	☐	Chronic bronchitis or other lung diseases	☐	☐
Epilepsy	☐	☐	Vibration white finger	☐	☐			
Migraines	☐	☐	Heart attack or disease	☐	☐			

HOW DO YOU RATE YOUR HEALTH AT THE MOMENT?

In general, would you say your health is: excellent ☐ very good ☐ good ☐ fair ☐ poor ☐

Compared to one year ago, how would you rate your health in general **now**?

much better now ☐ somewhat better now ☐ about the same ☐ somewhat worse now ☐ much worse now ☐

The following questions are about activities you might do during a typical day. Does your health **now** limit you in these activities? If so how much?

	yes, a lot	*yes, a little*	*no, not at all*
Moderate activities e.g. moving a table, pushing a vacuum, bowling, playing golf	☐	☐	☐
Climbing *several* flights of stairs	☐	☐	☐

During the **past 4 weeks,** have you had any of the following problems with your work or other regular daily activities as a result of your **physical health?**

	yes	*no*
Accomplished less than you would like	☐	☐
Were limited in the *kind* of work or other activities	☐	☐

During the **past 4 weeks,** have you had any of the following problems with your work or other regular daily activities as a result of your **emotional problems** (such as feeling depressed or anxious)?

	yes	*no*
Accomplished less than you would like	☐	☐
Did not do work or other activities as carefully as usual	☐	☐

How much bodily pain have you had during the **past 4 weeks?**

none ☐ very mild ☐ mild ☐ moderate ☐ severe ☐ very severe ☐

During the **past 4 weeks,** how much did the pain interfere with your normal work (including both work outside the home and housework)?

not at all ☐ slightly ☐ moderately ☐ quite a bit ☐ extremely ☐

These questions are about how you feel and how things have been with you during the **past month.** (*For each* question, please give the one answer that comes closest to the way you have been feeling)

How much in the last **month?**	*all the time*	*most of the time*	*a good bit of the time*	*some of the time*	*a little of the time*	*none of the time*
Have you felt calm and peaceful?	☐	☐	☐	☐	☐	☐
Did you have lots of energy?	☐	☐	☐	☐	☐	☐
Have you felt down hearted and depressed?	☐	☐	☐	☐	☐	☐
Has your health limited your social activities (like visiting friends or close relatives)?	☐	☐	☐	☐	☐	☐

Would you like to be sent a summary of the study results? yes ☐ no ☐

Thank you for completing the questionnaire. Please return it using the reply paid envelope supplied.

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6.2 APPENDIX 2: METHODOLOGY FOR THE CLINIC STUDY (PART 2)

This section describes the methodologies used in Part 2 of the study. An example of a typical test day is shown in Figure 11. The CFQ was completed when the subject first arrived for the study to prevent later tests influencing the subjects' response. Neuropsychological tests were typically performed in the morning before lunch.

Order of test day	***Duration of test (minutes)***
ARRIVE - Introduction	10
Consent form, CFQ, background questionnaire	5
National Adult Reading Test (NART)	5
CANTAB	60
BREAK	15
California Verbal Learning Test (I)	15
Questionnaires: HADS, PRMQ, DEX, SF-36, Lifestyle	20
California Verbal Learning Test (II)	10
Logical Memory (I)	15
Stabilometry test	10
Hearing test	20
Logical Memory (II)	10
LUNCH	30
Medical examination	60
Occupational history (incl. accident history)	45
WASI (2 subsets)	30
BREAK	15
Lung function tests (plus ALAPS questionnaire)	60
MRI (brain)	60
End of test day	

Figure 11 A standard test day in the clinic study (Part 2)

6.2.1 Health related quality of life questionnaires (SF-36 & SF-12)

SF-36 questionnaire: The SF-36 (105) is the most widely used generic HRQOL questionnaire. It measures the impact of physical and mental health status, independent of clinical diagnosis. It provides a general health outcome measure, which is not disease specific and is a sensitive and validated measure of total impact of current morbidity. This is particularly useful in making discriminations between groups in essentially healthy populations, such as in the present study. The SF-36 was developed specifically for the purpose of large group comparisons in which the focus is on overall physical and mental health outcomes. The validated UK version of SF-36 was used in the present study (106). Higher scores mean better quality of life. Ware *et al* (105) have suggested that a difference of more than 3-4 points between group mean scores is the minimum, which indicates a clinically significant effect.

***SF-12 Questionnaire*:** The SF-12 (107) questionnaire is a short version of the SF-36. The 12 items of the SF-12 questionnaire are expressed as two summary scales: Physical Component Summary Score (PCS) and Mental Health Component Summary Score (MCS) (56). The PCS and MCS scores are transformed to norm based scores, giving standardised scales with a mean (SD) of 50 (10) in the UK population. Higher scores mean better quality of life. Ware *et al* (105) have suggested that a difference of more than 3-4 points between group mean scores is the minimum which indicates a clinically significant effect. A difference of 3-4 points between group mean scores represents an effect of 0.2 to 0.4, regarded as minimum clinically significant effect in health outcome measurement (57).

6.2.2 Neuropsychological assessments

NATIONAL ADULT READING TEST (premorbid IQ) (108): Cognitive tests can only measure current levels of cognitive functioning. Thus, in cases where impairment is suspected, comparison is necessary between current level of functioning and premorbid level to indicate extent of deterioration. When no premorbid test results are available an estimate of premorbid IQ can be obtained from NART. This test of IQ produces scores that are largely resistant to central nervous system damage. NART is typically used for predicting premorbid IQ in neuropsychological testing and was used for the calculation of CANTAB normative data (based on Wechsler Adult Intelligence Scale (WAIS) full scale IQ from NART). The Wechsler Adult Intelligence Scale – Revised (WAIS-R) full scale IQ is believed to be a more accurate measure of IQ since revises scores to make the population mean 100. WAIS-R was used in this study as a measure of premorbid IQ. Both WAIS and WAIS-R are readily calculated from the number of errors on NART by the following equations:

WAIS full scale IQ = 127.7 – (0.826 x NART errors)
WAIS – R full scale IQ = 130.6 – (1.24 x NART errors)

WECHSLER ABBREVIATED SCALE OF INTELLIGENCE (WASI) (current IQ): This scale of intelligence was devised specifically to estimating 'current IQ' where time is a major constraint. The sub-tests load highly on general intellectual function and have a strong relationship with constructs of fluid and crystalline intelligence. It is a test of IQ that is sensitive to central nervous system damage. The 2 sub-test version (matrix reasoning and vocabulary) is a fast and valid method of estimating global intellectual function (FSIQ score). Matrix reasoning test provides a score of fluid intelligence and the vocabulary test a score of crystallised intelligence.

6.2.3 Objective neuropsychological tests

LOGICAL MEMORY: The Logical Memory is one of a battery of tests from the Wechsler Memory Scale-III (The Psychological Corporation, 1997). Logical Memory has been shown to be highly sensitive to mild brain injury (109), correlates well with performance in everyday situations (110) and has shown significant effects in divers with DCI (13). In addition there is evidence that performance on Logical Memory is associated with white matter lesions (111;112) and WMH have been suggested to be more common among divers (22;23;113;114) although there is controversy over this issue (28;29;115). Measures were selected in order to assess both immediate and delayed memory. Deficits in both immediate and delayed memory are associated with impaired encoding while delay only deficits are thought to be related to retrieval problems. A higher score reflects better recall.

CALIFORNIA VERBAL LEARNING TASK – II (CVLT-II): CVLT-II provides the opportunity for detailed level analysis into verbal learning and memory processes such as whether subjects use the most efficient strategy to complete the test. CVLT has been shown to be sensitive enough to predict the occurrence of Alzheimer's Dementia in non-clinical elderly individuals who were genetically at risk of developing the disease (116). Thus it is able to detect mild, sub-clinical deficits which evidence suggests may be the extent of deficit present in divers (9). Again, measures were selected to assess both immediate and delayed memory on this test for comparability with Logical Memory.

CAMBRIDGE NEUROPSYCHOLOGICAL TEST AUTOMATED BATTERY (CANTAB)

5 Choice Reaction Time (RTI): RTI was chosen since it is a more sensitive measure of psychomotor deficits than simple/one choice RT. RTI is also a test of divided attention (117).

Rapid Visual Processing (RVP): The RVP task assesses the ability to attend and respond to visual information presented rapidly (sustained attention). The measure, "a prime", used for analysis reflects the extent to which subjects performed optimally on this task. In addition vigilance (or sustained attention) has also been associated with WMHs (112;118;119).

Spatial Recognition Memory (SRM): This test was selected to assess memory in a visual and auditory modality. General memory impairment, if present, should be evident across both modalities. Furthermore there is evidence that suggests that diving can cause deficits in spatial memory (9).

Intradimensional-Extradimensional Shift (IDED): Difficulties in 'concentration' can result from an inability to disengage attention once focused. Thus complaints of poor concentration may conceivably result from impairment of attentional control mechanisms. This task measures the performance of these mechanisms, which are executive or frontal lobe functions, in stage 8 of the task (the extra dimensional shift). Frontal or executive functions have been suggested to be associated with WMH (120). Data from this task is analysed as percentage of groups passing and failing each stage where stage 8 is of most interest.

Stockings of Cambridge (SOC): This is a spatial planning test based on the Tower of Hanoi Test to test executive function (121). It is a test sensitive to frontal lobe lesions (122) and to fronto-striatal dysfunction (123). The number of problems solved in the minimum number of moves is the recommended fundamental test metric by CeNes, the test developers. The score used is based on the number of problems successfully completed in the minimum number of moves.

Spatial Working Memory (SWM): This is a test of executive memory. Memory functions that require constant feedback, monitoring and updating of progress are carried out through interaction of the frontal lobe with other memory systems situated in the temporal lobe. As with attention, complaints of poor memory may relate specifically to failure of executive memory rather than failure of memory processes sub-served by temporal lobe structures. The between search error metric is one commonly selected for analysis (122;124). The total number of between search errors is used as the score in this test.

6.2.4 Subjective neuropsychological questionnaires

Prospective Retrospective Memory Questionnaire (PRMQ) (125)***:*** This questionnaire assesses everyday memory failures. Confirmatory factor analysis of the PRMQ has confirmed that the questionnaire does assess a single common factor of memory but with significant additional factors of prospective and retrospective memory nested within this (126). Thus if prospective and retrospective scores are not significantly different, the single PRMQ total score is most appropriate for summarising performance on this questionnaire. Normative data is available in the form of T-scores (Crawford *et al.* p. 6 (126)).

Cognitive Failure Questionnaire (CFQ) (127): This questionnaire assesses self-reported failures of perception and motor behaviour in addition to memory failures. It has been shown to correlate more highly with executive functions rather than tasks of memory, and is argued to measure failure in the *control* of attention and memory (i.e. in the allocation of cognitive resources and sequencing of behaviours (127)). High CFQ scores are believed to be related to increased vulnerability to stress and have been shown to be significantly related to increased number of mishaps (such as hospitalisations, and being injured in a fall (128)). Furthermore, high level of subjective cognitive failures based on the CFQ have been associated with white matter lesions in the elderly (84).

Dysexecutive Function Questionnaire (DEX): This questionnaire forms part of the Behavioural Assessment of the Dysexecutive Syndrome test battery (Thames Valley Test Company, 1996). The questionnaire asks about 4 broad areas of executive dysfunction: emotional or personality changes, motivational changes, behavioural changes, and cognitive changes.

6.2.5 Hospital Anxiety and Depression Scale

This questionnaire was designed to identify cases of anxiety disorder and depression in non-psychiatric hospital clinic patients (129). Normative data is available for this questionnaire, specific to gender (130).

6.2.6 Armstrong Laboratories Aviation and Personnel Survey (ALAPS)

The ALAPS was developed for use in the US Air Force personnel (64). The questionnaire has been demonstrated to be reliable and valid (131;132). The full ALAPS consists of 15 scales that assess domains of personality, psychopathology and crew interaction style. In the scales the participant is asked to tick “True” or “False” against each statement. Although all of scales in the ALAPS had potential power for the present study, time constraints necessitated selection of a subset of scales. It was decided that the most relevant scales was the subset "Crew Interaction Scales" comprising 96 statements that measure 6 aspects of crew interaction style:

Dogmatism High scorers believe what they believe is always correct and are not open to change. They are authoritarian interpersonally. They are intolerant of other people, ideas, and actions

Deference High scorers are deferent to a fault. They are submissive and quiet. They concentrate on their job and are uncomfortable questioning the status quo.

Team Orientation High scorers enjoy and believe in teamwork. They value team effort and team rewards. They do not enjoy working alone and may be inefficient when working alone.

Organisation High scorers are systematic and organised. They co-ordinate and plan all elements of a project. They think things through thoroughly.

Impulsivity High scorers act first and think second. They often act and talk without sufficient forethought. They see themselves as spontaneous. Others may be less generous in their assessment and find them careless.

Risk Taking High scorers enjoy danger and risk. New activities and situations are not frightening. They are adventurous, unafraid, and fun loving. They are not necessarily impulsive about their activities; their actions may be calculated and include a rational appreciation of the inherent danger.

6.2.7 Medical examination

To reduce potential bias the medical examination was conducted by independent doctors recruited to the study and blind to the results of Part 1. Furthermore the doctors were not told whether the participant was a diver or an offshore workers and the examination was conducted before the medical history was taken to keep this concealed until the examination was complete.

The examination was primarily of the nervous and locomotor systems and blood pressure was measured (Critikon Dinamap). Afterwards a medical history was taken, which included details of current and past medical complaints, current symptoms, a systemic enquiry and details of any head injuries. For each medical complaint and symptom reported, the duration, progression, limit on daily activity and treatment were recorded. The number of head injuries and the duration of loss of consciousness associated with the head injury were recorded.

The questionnaires and protocols used in the medical examination are available on request.

6.2.8 Occupational History

A Consultant in Hyperbaric Medicine took a detailed occupational history for both divers and offshore workers:

Occupation: This section investigated current work status and description of current job, occupational history, exposures at work to substances and noise, recreational diving experience and work experience offshore (topside work, not diving offshore).

Diving Experience: Divers were asked for the duration of diving career and diving experience including the diving techniques they has used and the actual number of dives they had done during their diving career (including training).

Accidents: The final part of the interview investigated the number of lost time accidents (more than 3 days off work) during their career, minor injury (3 or less days off work) during the preceding year, number of days off work due to sickness in the preceding year and all diving related accidents.

6.2.9 Lung function tests

The lung test data were standardised for age and height. The following lung tests were conducted for all divers and offshore workers.

Peak expiratory flow (PEF) - the maximum rate of airflow that can be achieved during a sudden forced expiration from a position of full inspiration. PEF was measured using a Wright Peak Flowmeter (Ferraris Medical). The best result from three sequential measurements made over a period of 2 minutes was recorded.

The following values were recorded using a Vitalograph Alpha Spirometer:
Forced vital capacity (FVC) - the volume of air expelled by a forced maximal expiration from a position of full inspiration. FVC is reduced in both obstructive and restrictive respiratory disease.

Forced expiratory flow at 1 second (FEV_1) - the volume of air expelled in the first second of maximal forced expiration from a position of full inspiration. This is reduced in obstructive respiratory disease.
Forced expiratory volume/forced vital capacity (FEV_1/FVC) - The normal value for this ratio is above 0.70, though this is age dependent varying between 0.70 and 0.90. Reduction of the FEV_1/FVC ratio occurs in obstructive lung disease and may be increased to >0.85 in people with restrictive lung disease.
Flow rates at mid and low lung volume - these are the flow rates measured at 50 and 25% of the forced vital capacity during a forced expiratory manoeuvre (**FEF25%** and **FEF50%**).

Gas exchange
Diffusing capacity for carbon monoxide **DLCO** and transfer coefficient **KCO** (diffusing capacity per unit lung volume) were used as a measures of gas exchange capacity of the lungs. This was measured using the standard single breath technique.

Total Lung Capacity and Residual Volume
Total Lung Capacity (TLC) is the volume of gas contained in the lung after a full inhalation. Residual volume (RV) is the volume of gas remaining in the lung following a maximal expiration. Expiration is limited by closure of small airways and as a result residual volume increases in diffuse airway obstruction. Residual volume/total lung capacity ratio (RV/TLC) also provides an indication of airway obstruction.

Reliability of the lung function tests: As a quality control measure for the lung function tests, the results from non-smokers in the control group (offshore workers) were compared to predicted values (based on age and height) using ECCS prediction equations for all parameters with the exception of FEF25% and FE50% where predicted values from Cotes (133) were used (Table 39). Although this sample is not a truly random sample of the population, but provides a good indication of the performance of the lung tests. The values in Table 48 are the percentage of the predicted values, therefore 100% would be the expected value. These results suggest that the lung tests were reliable, with slightly reduced values for FEF25% and FE50% and inflated values for KCO.

Table 48 Percent-predicted values for offshore workers who had not smoked

	% predicted values for offshore workers (non smoker (n =53)) mean (95% CI)
PEF	106.6 (102.2-110.9)
FVC	100.2 (96.6-103.9)
FEV_1	94.9 (90.9-98.8)
FVC/FEV_1	97.4 (94.7-100.0)
FEF25%	84.6 (77.2-92.1)
FEF50%	86.5 (79.5-93.5)
TLCO	96.8 (94.2-99.5)
KCO	113.8 (109.7-118.0)
TLC	93.6 (90.2-96.9)
RV	94.6 (89.1-100.1)
RV/TLC	97.5 (92.1-103.0)

6.2.10 Brain MRI score scale

Described in Table 49 is the scoring system developed by Dr A.R. Denison and Dr A. Murray, Department of Radiology, University of Aberdeen, for the scoring of divers and offshore workers MRI brain scans.

Table 49 Scoring scale for MRI

Score	*Size of hyperintensities*	*Number of hyperintensities*
0	normal	-
1	≤ 3mm	≤ 5
2	≤ 3mm	≥ 6
3	4-10 mm	≤ 5
4	4-10 mm	≥ 6
5	≥ 11 mm	≥ 1
6	confluent	-

Measurements:

1. **White matter hyperintensities** (score 0-6 in each region with max score 30)
   REGIONS: Frontal lobe, Parietal lobe, Temporal lobe, Occipital lobe, Internal capsule

2. **Grey matter hyperintensities** (score 0-6 in each region with max score 30)
   REGIONS: Canudate nucleus, Putamen, Globus Pallidus, Thalamus, Hippocampus

3. **Infra-tentorial foci of hyperintensity** (score 0-6 in each region with max score 24)
   REGIONS: Cerebellum, Midbrain, Pons, Medulla

4. **Periventricular hyperintensities** (absent =0, present =1)
   REGIONS: Frontal horns, Body, Occipital horns

6.3 APPENDIX 3: MEDICAL COMPLAINTS CODED USING THE ICD-9

ICD-9 codes	***Medical complaints presented by divers and offshore workers***
1. Infectious & parasitic diseases	fungal nail infection, verucca, fungal infection, hepatitis B
2. Neoplasm	throat cancer, lymphoma, leukaemia
3. Endocrine, nutritional/metabolic diseases & immunity disorder	hypercholesterolaemia, hypothyroid, hyperthyroid, diabetes, obesity, gout
4. Disease of the blood & blood-forming organs	Vitamin B12 deficiency
5. Mental disorder	depression, alcohol abuse, stress, repeated trauma
6. Disease of the nervous system & sense organs	Parkinson's disease, hearing problems (NIHL, deaf in one ear, ear infection, impaired hearing, high tone hearing loss, perforated ear drum, tinnitus, ruptured tympanic membrane), glaucoma cataracts, corneal ulcer, median nerve damage, epilepsy, migraine
7. Disease of the circulatory system	hypertension, varicose veins, vibration white finger, angina, atherosclerosis, extra heart beat, CHD, Reynaud's phenomenon, left coronary artery stenosis and TIA's, atrial flutter, aortic valve replacement, poor circulation, heart valve, piles
8. Disease of the respiratory system	allergic rhinitis, conjunctivitis, viral URTI, hayfever, smoking, sinusitis, chest infection, right nasal polyp
9. Disease of the digestive system	heartburn, hiatus hernia, irritable bowel syndrome, reflux, gallstones, peptic ulcer, gastro-oesophaegal disease, coeliac disease, colitis, inguinal hernia
10. Disease of the genitourinary system	kidney stones, Peyronie's disease, prostatitis, retroperitoneal fibrosis, incontinence,
12. Disease of the skin & subcutaneous tissue	eczema, dermatitis, psoriasis, acne rosacea
13. Disease of the musculoskeletal system & connective tissue	degenerative disease, musculoskeletal, calcification of medial ligament, post-operationive problems to R shoulder after road traffic accident, wear/tear, spinal surgery, twisted vertebrae, muscular tension, disc problems, arthritis, chronic pain syndrome, torn cartilage, psoriatic arthritis, tendonitis, rheumatoid arthritis, osteoarthritis, psoriatic arthropathy, bursitis, right clavicular atrophy, cartilage problems, ankylosing spondylitis, sprained neck, achilles tendonitis, left rotator cuff problem, prolapsed intervertebral discs, cervical spondylosis, back muscle spasms (trapped nerve), RSI, fractures (#T6, #clavicle, #tibia in 3 places, 3 crushed vertebrae, #knee, #L4, #pelvis, #ankles, transection T12-L1, paralysis, crushed lower disc L5, #back, 3 fractures at MTP joint,) collapsed arch in left foot
14. Congenital anomalies	spina bifida (mild)

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