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Factors which could influence Diver Performance on Neurological Investigation

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Factors which could influence Diver Performance on Neurological Investigation

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SUMMARY

The aims of this study were twofold. To ascertain whether history of untreated or unreported DCI and/or the presence of a PFO had influence on diver performance on neurological investigation. In a previous study, divers who had suffered untreated or unreported incidents of DCI (n=12) were found to have a significantly poorer performance on neuropsychometric assessment, especially in tests of short-term memory, than divers (n=19) who had history of only treated DCI (Duff *et al.* 1996). This document reports the findings of the effect of history of untreated or unreported DCI on diver performance on neurophysiological assessment, neurological examination and texture analysis of HMPAO-SPECT brain image in comparison to divers with history of only treated DCI. With regard to the effect of presence or absence of PFO, in addition to the above investigations, neuropsychometric performance was also examined. Groups were examined for comparability with regard to age, diving history, severity of DCI history and lifestyle.

In general in all investigations, the groups were comparable with regard to age, diving history and alcohol consumption. A greater number of individuals in the group with history of only treated DCI had used drugs of abuse and a higher percentage had suffered a DCS type 2. Analyses of results in the absence of individuals with history of significant head injury, showed little variation to total group analyses.

No significant difference was found between groups with regard to MGL of HMPAO-SPECT brain image. Divers with history of only treated DCI had the lower MGL possibly reflecting the greater number of divers in this group (11/14 compared to 3/8) who had suffered a DCS type 2 incident.

In comparison of the results of neurophysiological assessment, group total numbers were insufficient for valid statistical analysis apart from total measures on Tibial SEP where no significant difference was detected (X^2 test;p>0.05). Following stimulation of the Median nerve, divers with history of untreated or unreported DCI have a higher percentage abnormal. With regard to measurement of Brainstem Audio EPs, both groups have a similar level of abnormality.

There is no difference between groups with or without history of untreated or unreported DCI in the detection of significant abnormality on clinical examination. Group numbers are too small for valid statistical analysis. Divers with history of only treated DCI had greater abnormality in the area of response to sensation whereas divers with history of untreated or unreported DCI had greater abnormality in reflex response.

In general, on examination of the effect of presence of PFO on neurological investigation, total group numbers are too small for valid statistical analysis or conclusions to be drawn especially with regard to divers with neither DCI history nor presence of PFO.

On examination of neuropsychometric test performance, no significant difference was found between matched pairs of divers with PFO or no detected PFO on any test. Divers were matched with respect to age within 2 years, years of education, intellectual ability, diving and DCI history.

Similarly, on comparison of matched pairs of divers with PFO or no detected PFO with regard to MGL of HMPAO-SPECT brain image, no significant difference was found. In analysis of matched pairs of divers, divers with PFO have a higher percentage abnormality on Median nerve stimulation.

With regard to results of the clinical examination, no difference was noted between divers with respect to presence or absence of PFO. Divers with PFO tended to have a greater abnormality in reflex response.

In conclusion, in contrast to the earlier finding of an effect of history of untreated DCI on neuropsychometric test performance, history of untreated DCI has no effect on diver performance on the neurological investigations studied here. Similarly, presence of PFO also has no effect on diver performance on neurological investigation. However, the validity of the conclusions drawn is questionable due to the small group size under analysis and in some instances, group comparability. The comparisons require to be carried out on a much larger population.

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1. AIMS OF THE PROJECT

1. AIMS

The project has two aims:

1. To ascertain whether history of untreated DCI has an influence on the findings of the neurophysiological measurement, texture analysis of HNIPA0-SPECT brain image and clinical examination of commercial divers.

2. To investigate whether the presence of PFO has an effect on diver performance on neurological investigation.

2. INTRODUCTION

2.1 Background

Diving exposes the individual to the risks of breathing gas at raised environmental pressure. In recent years, there has been growing concern within the diving community that divers may be suffering long-term neurological damage as a result of decompression illness (DCI) and possibly even as a result of prolonged exposure to compressed air diving.

The pathogenesis of DCI is not fully understood. It has become well established that the production of gas bubbles within body tissues is the initiating factor for the development of DCI; however, both the underlying mechanism and the site of bubble production within the body tissues remain unclear. Gas bubbles may be liberated from solution following exposure to increased ambient pressure at depth with a subsequent reduction in pressure on return to the surface. Formation of 'silent' bubbles of nitrogen following a dive is a well recognised phenomenon. These bubbles produce no detectable symptoms, but are present in the blood stream as has been demonstrated under many practical diving conditions using Doppler and ultrasonic scanning (Nishi 1993). In the majority of cases, these gas emboli are filtered by the pulmonary capillaries and are not associated with overt symptoms.

Inert gas bubbles may be either intravascular or extravascular and could disrupt tissue function in a variety of mechanical and biochemical ways (Vann & Thalmann 1993) producing sub-clinical damage. There is speculation as to whether recovery from such damage occurs, and if not, the implications for a cumulative effect which may eventually be shown as overt symptoms, may be argued. The nervous system is a favoured site for acute manifestations of DCI suggesting that it may be at particular risk of bubble induced injury (Elliott & Moon 1993).

This theory is supported by the results from histopathological studies, possibly the most accurate indicator of long-term neurological consequences of diving. Both in animal and human studies, there is evidence of persistent damage to the nervous system at post mortem despite good functional recovery from DCI. It was thought that this damage was bubble induced (Calder 1992). This raised the possibility that, if these clinically silent neurological lesions could exist in divers following DCI, they might also be occurring in divers who had never demonstrated overt symptoms of the condition. Indeed, spinal cord degeneration was observed by Palmer *et al*. (1987) in 3 out of 8 professional divers who had died accidentally from diving or non-diving accidents and who had no DCI history or neuroabnormalities. There was also histological evidence in both amateur (5 out of 12) and professional divers (11 out of 13) of diffuse damage to small cerebral vessels which affected both grey and white matter (Palmer *et al*. 1992). In another neuropathological study, Morild and Mork (1994) reported a significantly higher loss in ependymal cells lining the ventricles in the brains of divers (n = 2 1) compared to controls (n = 15).

A variety of increasingly sensitive techniques has been used to investigate for the presence or absence of subclinical nervous tissue damage in divers and has indicated that neurological change may be occurring. Earlier studies using neuropsychometry, which reported an association between intellectual impairment and neurological decompression sickness (DCS - original terminology for DCI), were criticised for limitations in diagnostic categories, statistical analysis and use of control groups (Edmonds & Hayward 1987). More recent studies on abalone divers who carry out a unique and extremely provocative diving procedure, have suggested that there is a correlation between impairment of certain neuropsychological functions with diving and various parameters of DCI (Williamson *et al*. 1987, 1989) although Andrews *et al*. (1986) had concluded there was no evidence of a subset of divers with abnormal scores and no evidence for accumulation of sub-clinical insults leading to a dementing process.

In other investigations, McQueen *et al*. (1994) reported an increase in reported symptoms of ill-health in recreational divers as total career dives and number of dives in the previous 12 months increased; however, some of these divers also had DCI history. Reul *et al*. (1995) reported an increase in MRI detected focal lesions in 52 amateur divers compared to controls, however, the number of divers with symptoms of DCI is unknown and they found no correlation with diving history.

A study of the potential long-term neurological consequences of DCI was completed in 1994 by the Hyperbaric Research Unit (Shields *et al*. 1996). Groups of offshore commercial divers, with and without history of DCI, were subjected to a series of clinical neurological investigations and the results were compared to a group of non-diving control subjects. Clinical investigations involved the use of neurophysiological assessment, neuropsychometric assessment, neurological examination and HMPAO-SPECT brain imaging. A high incidence of abnormality of response was detected in divers compared with non-divers. It was further observed that divers (31 in each group) who had experienced DCI showed a greater incidence of abnormality than divers with no DCI history.

On neurophysiological assessment, a higher proportion of abnormal evoked potential measurements were recorded in divers with history of DCI (eg somatosensory evoked potential, tibial nerve stimulation - 14 x standard data) but divers with no DCI history were also found to have an elevated level of abnormal neurophysiological responses (eg SEP, tibial nerve stimulation - 7 x standard data; Shields *et al*. 1996). A similar observation of abnormal neurophysiological responses in divers with no history of treated DCI, was made by Elliott *et al*. 1994.

Clinical neuropsychometry is concerned with assessment of the behavioral expression of brain dysfunction which is suggested by inconsistent performance across a variety of tests examining a range of behaviours (Davison & Neale, 1990; McCarthy 1990). On neuropsychometric assessment, divers with DCI history had a statistically significant poorer logical memory performance than non-diving controls on immediate recall and also than divers with no DCI history on delayed recall. In a concurrent study at this Unit, which examined the neurological consequence of DCI

in a mixed population of recreational and professional divers (Evans 1994), decrements in performance were again found on testing of logical memory and verbal fluency in divers with DCI history compared to non-diving control subjects.

Using the recently validated technique of first-order texture analysis of $^{99}Technetium^{m}$-Hexamethyl Propylene Amine Oxime-Single Photon Computerised Tomography (HMPAO-SPECT) brain images (Staff *et al*. 1995, 1996, Shields *et al*. 1997) which provides an objective measure of cerebral perfusion in the form of mean grey level (MGL), cerebral changes were measured in divers compared with non-divers and more especially in divers with history of DCI. Results using this technique of texture analysis of HMPAO-SPECT brain images have also indicated that divers with more than 14 years professional diving experience or more than 100 'decompression days' per year in career, have a significantly lower MGL value which is indicative of an abnormal brain image.

2.2 HISTORY OF UNTREATED DCI

In the study into the potential long-term neurological consequences of DCI, no association could be found between the results of the neurological investigations and an index of severity of DCI history (Shields *et al*. 1996). The index of severity was created by an experienced diving physician and was based on the original classification of the incidents into decompression sickness type (ie DCS type 1 or type 2), symptomatology, the number of incidents in a diver's career and whether the individual suffered residua.

On further examination of a diver's DCI history, it was noted that some individuals had suffered untreated or unreported episodes. Untreated symptoms of DCI could increase the extent of neurological impairment in divers by increasing the likelihood of the presence of gas emboli in the circulation and tissues for an extended time period. Brubakk *et al*. (1994) examined the results of a questionnaire sent to inshore air divers, offshore divers and sports divers in Norway and reported a correlation between divers who had suffered untreated incidents of DCI and subjective reported problems with concentration, memory, irritability and depression.

Of the 31 divers who had taken part in the study on the potential long-term neurological consequences of DCI, 12 were found to have history of untreated episodes and 19 had history of only treated DCL. On comparison of the results of the neuropsychometric assessment of these divers, divers who had suffered untreated or unreported incidents of DCI had a significantly poorer neuropsychometric test performance, especially in tests of short-term memory, than divers who only had history of treated incidents (Duff *et al*. 1996). They also had a significantly poorer performance on a test of verbal fluency and another which measured current intelligence.

In contrast to the findings of Brubakk *et al*. (1994), no difference was found between groups with regard to subjective reports of problems with memory, concentration and depression. In response to the question of irritability, it was divers with history of only treated DCI who reported the greater number of problems (26% compared to 8%). This finding was further supported by the similar response of both groups to

the Cognitive Failures Questionnaire, which assesses self-reported. failures of perception, memory and motor function in daily life. However, 6 of the divers had reported a previous head injury which could be classified as significant and in order to remove any influence of this confounding factor on neuropsychometric test performance, the results were reanalysed in the absence of these individuals. The findings of this analysis were exactly the same as previously, ie divers with history of untreated DCI had a significantly poorer neuropsychometric test performance (Duff *et al*., unpublished observation).

2.3 PRESENCE OF PATENT FORAMEN OVALE (PFO)

The presence of a PFO has been implicated as a possible contributory factor to the occurrence of neurological decompression illness especially when the incident dive appears non-provocative. In the foetus, the foramen ovale is an inter-atrial channel which allows passage of blood from the right to the left side of the circulation bypassing the lungs. In a diver under hyperbaric conditions, incomplete closure of this channel after birth, could allow passage of venous gas emboli into the arterial circulation where the bubbles could cause damage in neurological tissue. It is therefore possible that the presence of PFO could increase the extent of neurological impairment in divers by increasing the likelihood of the presence of gas emboli in the circulation and tissues.

Incomplete closure of this channel is know to occur in a significant proportion of the population. In a post mortem study of 965 healthy human hearts, patent foramen were reported in 27.3% of subjects (Hagen *et al*. 1984). Studies carried out by Moon *et al*. (1989, 1991) and Wilmshurst *et al*. (1989,1990) have lead to reports of a higher than expected prevalence of PFO in divers with a DCI history. However, Cross *et al*. (1992a) reported finding a prevalence of PFO in 33% (26 out of 78) of divers who had never experienced DCL

As part of the study of the potential long-term neurological consequences of DCI by Shields *et al*. (1996), subjects were also examined by echocardiography to detect the presence of a PFO in order to try to determine the extent of any contribution of this factor to the occurrence of DCI. Divers with history of DCI were found to have a proportionately greater presence of PFO (41.4%) than divers with no DCI history (18.5%). However, there was no difference between divers with history of DCI and non-diving controls (39%) as reported by Cross *et al*. (1992b). No conclusion could therefore be drawn on the contribution of this factor to the occurrence of DCL

3. RESEARCH DESIGN

Since the production of gas bubbles within body tissues would seem to be the initiating factor for the development of DCI and in a previous study, divers with history of DCI were found to have a significantly poorer performance on neurological investigation (Shields *et al*. 1996), this raised the question as to whether the extent of neurological impairment would be increased in divers with history of untreated or unreported DCI and/or the presence of PFO since both these factors could increase the likelihood of the presence of gas emboli in the circulation and tissues. This proposal was supported by the finding that divers with history of untreated or unreported DCI had a significantly poorer performance on neuropsychornetric testing than divers with history of only treated DCI (Duff *et al* 1996).

This study examines:

1) the extent of effect that history of untreated or unreported DCI has on the results of the other neurological investigations carried out in the earlier study on the same set of individuals, ie evoked potential measurement, texture analysis of HMPA0 SPECT brain image and clinical examination.

2) the effect of PFO on the results of the neurological investigations. In the earlier study, divers both with and without history of DCI were also examined by echocardiography for the presence of a PFO. The results of the neurological investigations, including neuropsychometric test performance and subjective reports of long-term health, will be compared for divers both with and without PFO.

In this study, particular attention will be paid to the comparability of the subject groups with regard to age, history of DCI and diving, significant head injury and lifestyle factors which could effect performance on neurological investigation.

4. PROCEDURE

4.1 SUBJECTS

4.1.1 Divers with history of untreated DCI

The 31 divers with history of DCI who had taken part in the earlier study (Shields *et al*. 1996) had been questioned both at interview by a clinician experienced in diving medicine and by questionnaire on any untreated or unreported symptoms of DCI. Nineteen divers had history of only treated DCI and 12 were found to have history of untreated or unreported incidents.' Details of these incidents are shown in Table 1.

Table 1
Details on Untreated or Unreported DCI

Diver	Number of Episodes	Symptoms	Date/ Location	Reported/Treated
A	Many	Rash/Niggle	Unknown	Unreported
B	Many	Rash/Niggle	UP to 1990	Unreported
C	Many	Skin	Unknown	Unreported
	1	Pain	1980/Abroad	Reported/not treated
D	5	Pain	Unknown	Unreported
E	3	Rash/Niggle	1980-82/Abroad	Reported/not treated
F	3	Skin	1982-87/UK	Reported/not treated
G	1	Vomiting/ Disorientated	1976/Abroad	Not treated
	1	Rash/Niggle	1983/UK	Unreported
	1	Rash/Niggle	1993/Abroad	Reported/not treated
H	1	Rash	1983/Abroad	Not treated
I	1	Itch	1983/UK	Reported/not treated
J	1	Pain	1989/UK	Reported/not treated
K	1	Pain	1990/IJK	Unreported
L	1	Rash/Niggle	1993/Abroad	Unreported

Divers who reported 'many' incidents could not give details on dates, location, type of dive or particular symptoms. Episodes noted in the table where date and location are known, all occurred on air/nitrox dives. Almost all episodes noted as occurring in the UK, were in the North Sea and those abroad were in Africa, Far East, Persian Gulf or another sector of the North Sea.

4.1.2 Divers with PFO

Of the 62 divers (31 with DCI history; 31 with no history of DCI) who had taken part in the earlier study, 2 did not wish to be examined by bubble contrast echocardiography, in one case the procedure could not be carried out and in 3 additional cases, the outcome could not be visualised. The procedure and details of this investigation are as stated in Shields *et al*. (1996). A PFO was detected in 17 divers with DCI history and in 5 with no history of DCI. No PFO was detected in 12 divers with DCI history and 22 divers with no history of DCI.

4.1.3 Subject Information

Subjects volunteered to take part in the clinical investigations and not all subjects wished to take part in all investigations, therefore the total number of subjects involved in each investigation varies. Details on lifestyle factors, ie alcohol consumption, usage of drugs of abuse and history of head injury or problems with regard to long-term health were elicited by questionnaire and confirmed at interview.

4.2 CLINICAL INVESTIGATIONS

The neurological investigations to be studied are neuropsychometry, neurophysiology, Tc^{99} -HMPAO-SPECT, clinical examination and for detection of PFO, bubble contrast echocardiography. The results of all clinical investigations and details on methodology are as stated in Shields *et al*. (1996). This study is simply a reanalysis of the results. With regard to the texture analysis of HMPAO-SPECT brain image, details of measurement can be found in Staff *et al*. (1995) and results in Shields *et al*. (1997).

4.3 STATISTICAL ANALYSIS

Parametric tests - such as one or two tailed t tests were used as appropriate. A X^2 test was used to examine differences in assessment. A probability of <0.05 was taken as the criterion for there being a significant difference. On occasion, statistical analysis was not undertaken due to the small size of the groups.

Where there seemed to be a significant difference between groups, subjects were matched with regard to age within 2 years, presence or absence of DCI history and diving history. In addition, when neuropsychometric test performance was being compared, subjects were required to be matched with regard to years of education and intellectual ability as measured by the NART

5. RESULTS - HISTORY OF UNTREATED DCI

5.1 MGL of HMPAO-SPECT BRAIN IMAGE

Divers with history of only treated DCI have a lower MGL, of HMPAO-SPECT brain scan than divers with history of untreated DCI (Table 2). This difference is not significant (one-tailed *t* test,df=20;*p*>0.05).

Table 2
MGL of HMPAO-SPECT Brain Image

Group	MGL	Age
Untreated (n=8)	6.13±0.79 (4.45-7.07)	37.3±6.9 (26-49)
Treated (n= 14)	5.91±0.89 (4.11-7.71)	37.6±4.2 (32-50)

5.1.1 DCI Severity Index

Divers with history of only treated DCI have higher scores on the DCI Severity Index (Table 3). Only 3/8 divers with history of untreated DCI had suffered an incident of type 2 DCS compared to 1 l/14 with history of only treated incidents.

Table 3
DCT Severity Index

Group	1-4	5-6	8-10
Untreated (n=8)	5(62.5%)	1(12.5%)	2(25%)
Treated (n= 14)	3(21%)	5(36%)	6(43%)

5.1.2 Diving History

There is no significant difference between groups (two-tailed *t* test,df=20;*p*>0.05) with regard to diving history (Table 4).

Table 4
Diving History

(Mean/Individual)	Untreated (n=S)	Treated (n=14)
Years Professional Diving	13.3±5.1 (8-23)	14.7±2.9 (10-20)
Career Dives	996±437 (501-1700)	1043±604 (406-2190)
Dives/Year	73±13 (55-89)	68±27 (34-110)
Decompression Days	1044±429 (505-1700)	1179±608 (560-2526)
Decompression Days/Year	77±13 (63-99)	77±26 (43-126)

5.1.3 Alcohol Consumption

There is very little difference between groups with regard to alcohol consumption. A slightly greater number of divers with history of only treated DCI had a previously higher level of alcohol consumption. Level of consumption is measured in units per week for each individual as described by Shields *et al*. (1996).

Table 5
Individual Alcohol Consumption per Week

Level (units)	Untreated (n=8)	Treated (n=14)
A (1-10)	3(37.5%)	6(43%)
B (11-20)	3(37.5%)	4(29%)
C (21-40)	2(25%)	3(21%)
D (41-80)	-	1(7%)

Years of Alcohol Consumption -
Untreated (n=8) = 19.6±7.0 (9-3 1): Treated (n= 14) = 19.9±5.0 (11-3 5)

Average Alcohol Consumption (units/week/individual) -
Untreated (n=8) = 16.0 : Treated (n=14) = 18.1

Previous Higher Level of Alcohol Consumption -
Untreated (n=8) = 4 (50%): Treated (n=14) = 9 (64%)

5.1.4 Usage of Drugs of Abuse

Ten divers (7 1 %) with history of only treated DCI have used drugs of abuse compared to 3 (37.5%) with history of untreated DCI. Hard drugs were used by 4 divers with history of only treated DCI.

5.1.5 Subjective Reports of Long -Term Health

A greater number of reports of problems with concentration, irritability and depression were reported by divers with history of only treated DCI (Table 6).

Table 6
Reports of Long-term Health

	Untreated (n=8)	Treated (n=14)
Concentration	1(12.5%)	3(210%)
Memory	4(50%)	8(58%)
Irritability	-	5(36%)
Depression	1(12.5%)	3(21%)

5.1.6 Head Injury

One diver in each group had reported a possible significant head injury. On removing these two divers from the analysis, there is no significant difference between groups (one tailed *t* test,df=18;*p*>0.05). Divers with history of only treated DCI have a lower MGL (Table 7) and a higher score on the DCI Severity Index (Table 8).

Table 7
MGL of Divers with no Significant Head Injury

Group	MGL	Age
Untreated (n=7)	6.16±0.84 (4.45-7.07)	38.0±7.1 (26-49)
Treated (n= 13)	5.90±0.93 (4.11-7.71)	38.1+4.1 (34-50)

Table 8
DCI Severity Index

Group	1-4	5-6	8-10
Untreated (n=7)	4(57.1%)	1(14.3%)	2(28.6%)
Treated (n= 13)	3(23.1%)	5(38.5%)	5(38.5%)

5.1.7 Age Matching

On matching pairs of divers (n=7) for age and diving history, there is no significant difference in MGL between groups (*t* test,df=6;*p*>0.05). Divers with history of only treated DC have a lower NIGI, (Table 9) and a higher score on the DC severity index (Table 10).

Table 9
MGL of Age-Matched Pairs

Group	MGL	Age
Untreated (n=7)	5.99±0.74 (4.45-6.76)	38.9±5.7 (32-49)
Treated (n=7)	5.61±0.27 (5.26-6.07)	38.4±5.8 (32-50)

Table 10
DCI Severity Index

Group	1-4	5-6	8-10
Untreated (n=7)	5(71%)	1(14%.)	1(14.)
Treated (n=7)	1(14%)	2(29%)	4(57%)

5.2 NEUROPHYSIOLOGY

Following stimulation of the Median nerve (Table 11), divers with history of untreated DC have a higher percentage of abnormal results compared to divers with history of only treated DCL With regard to measurement of Brainstern Audio EPs, both groups have a similar result. There is no significant difference in age between groups (two-tailed *t* test,df=26;*p*>0.05). There are insufficient total numbers in the groups for the results to be examined by statistical analysis apart from total measures on the Tibial SEP where no significant difference between groups was found (X^2 test;*p*>0.05.)

Table 11
Evoked Potential Measurement

	Untreated (n=10)	**Treated (n=18)**
BAEP - Subjects	2/9 + 1B (22%)	5/18(28%)
- Measures	2/50 + 1B (4%)	8/108 + 1B (7%)
Median - Subjects	5/10(50%)	4/18(22%)
- Measures	8/40(20%)	5/70(7%)
Tibial - Subjects	5/10(50%)	8/18 ± 1B (44%)
- Measures	10/29 (34.5%)	14/52 + 213 (27%)
Age (years)	37.4±4.6 (31-48)	37.0±4.1 (31-49)
- n=9	37.2±+4.9 (31-48)	

5.2.1 Distribution of Measured P40 Latency Relative to Expected Value

On further examination of the Tibial SEP results by comparison of expected P40 with measured P40 (Figure 1), the group with history of untreated DCI have a higher percentage of measured P40 values which are lower (ie faster) than expected (20% cf 11%) and a similar percentage which are longer than the ULN (35% cf 3 1%) compared to the group with history of only treated DCI. This comparison, however, does not include any abnormality detected in the difference between R and L P40 in an individual.

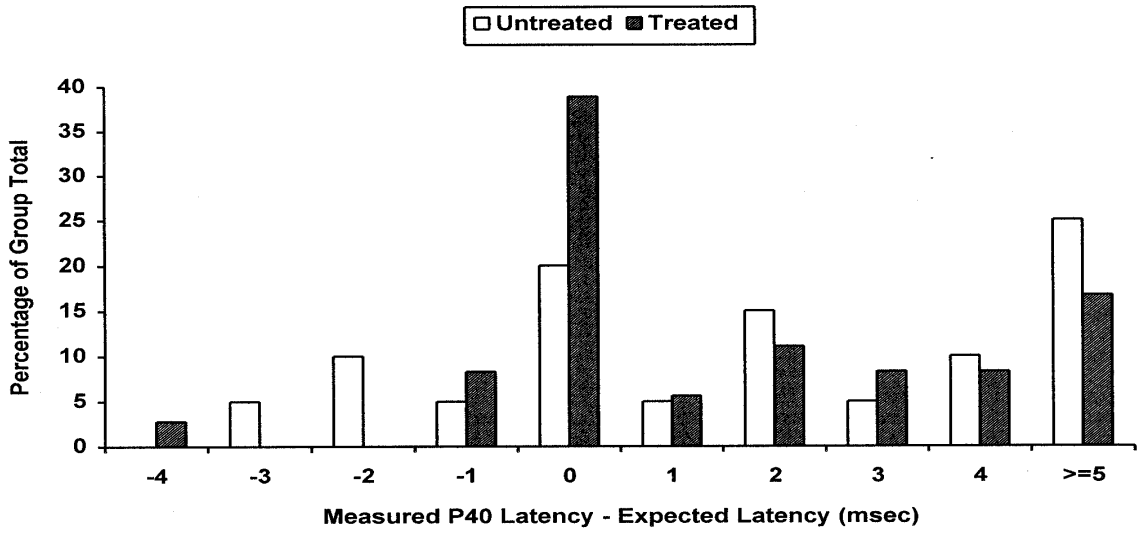

Figure 1 **Measured P40 Latency Relative to Expected Value**

5.2.2 DCI Severity Index

There is a slightly higher percentage of divers with history of treated DCI (Table 12) who have suffered a DCS type 2 incident (67% compared to 50%).

Table 12
DCI Severity Index

Group	1-4	5-6	8-10
Untreated (n= 10)	5(50%)	2(20%)	3(30%)
Treated (n= 18)	6(33%)	5(28%)	7(39%)

5.2.3 Diving History

Table 13 displays the diving history of the groups. There is no significant difference Between groups with regard to diving history (two-tailed *t* test;df=26;*p*>0.05).

Table 13
Diving History

(Mean/Individual)	Untreated (n=10)	Treated (n=18)
Years Professional Diving	12.8±5.4 (5-22)	14.3±3.2 (8-21)
Career Dives	896±419 (341-1638)	1048±591 (406-2187)
Dives/Year	70±15 (41-91)	72±33 (34-144)
Decompression Days	964±422 (341-1638)	1169±604 (560-2511)
Decompression Days/Year	75±13 (61-103)	81±32 (43-159)

5.2.4 Alcohol Consumption

There is no difference between the groups with regard to alcohol consumption. The level of alcohol consumption per week for each individual is shown in Table 14.

Table 14
Individual Alcohol Consumption per Week

Level (units)	Untreated (n=10)	Treated (n=18)
A (1-10)	5(50%)	9(50%)
B (11-20)	3 (30%)	5 (28%)
C (21-40)	1 (10%)	3(17%)
D (41-80)	1(10%)	1(6%)

Years Alcohol Consumption -
Untreated (n=10) = 20.7±5.1(14-3 1) : Treated (n=l 8) = 20.3±4.7(11-35)

Average Alcohol Consumption (units/week/individual) -
Untreated (n= 10) = 17.0 : Treated (n= 18) = 16.0

Previous Higher Level of Alcohol Consumption -
Untreated (n= 10) = 6 (60%) : Treated (n= 18) = 12 (67%)

5.2.5 Usage of Drugs of Abuse

Thirteen divers (72%) with history of only treated DCI have used drugs of abuse compared to 3 (30%) with history of untreated DCI. Hard drugs had been used by 4 divers with history of only treated DCI.

5.2.6 Subjective Reports of Long -Term Health

There is very little difference between groups with regard to subjective reports of problems with concentration, memory and depression (Table 15). Divers with history of only treated DCI reported a greater problem with irritability.

Table 15
Reports of Long-term Health

	Untreated (n=10)	Treated (n=18)
Concentration	3(30%)	5(28%)
Memory	6(60%)	11 (61%)
Irritability	1(10%)	7(39%)
Depression	2(20%)	5(28%)

5.2.7 Head Injury

Five subjects reported a head injury which could be classified as significant. On removal of these subjects from the analysis, there is very little change in results (Table 16). There is no significant age difference between groups (two-tailed *t* test,df=21,*p*>0.05).

Table 16
Evoked Potential Measurement

		Untreated (n=9)	Treated (n=14)
BAEP	- Subjects	2/8 + lB (25%)	3/14(21%)
	- Measures	2/44 + 1 B (4.5%)	6/84 + 1B (7%)
Median	- Subjects	5/9(56%)	4/14(29%)
	- Measures	8/36(25%)	4/54(7%)
Tibial	- Subjects	5/9(56%)	5/14 + 1B (38%)
	- Measures	10/26 (38.5%)	8/41 + 213 (19.5%)
Age (years)		38.1±4.3 (34-48)	37.1±4.1 (32-49)
	- n=8	38.0±+4.6 (34-48)	

The group total numbers are too small for valid statistical analysis apart from total measures on the Tibial SEP where no significant difference was found (X^2 test;*p* >0.05).

On comparison of tibial SEP expected P40 with measured P40 (Figure 2), the group with history of untreated DCI have a higher percentage of measured P40 values which are lower (ie faster) than expected (17% cf 7%) and a higher percentage which are longer than the ULN (39% cf 29%) compared to the group with history of only treated DCI. This latter difference is not significant (X^2,p>0.05).

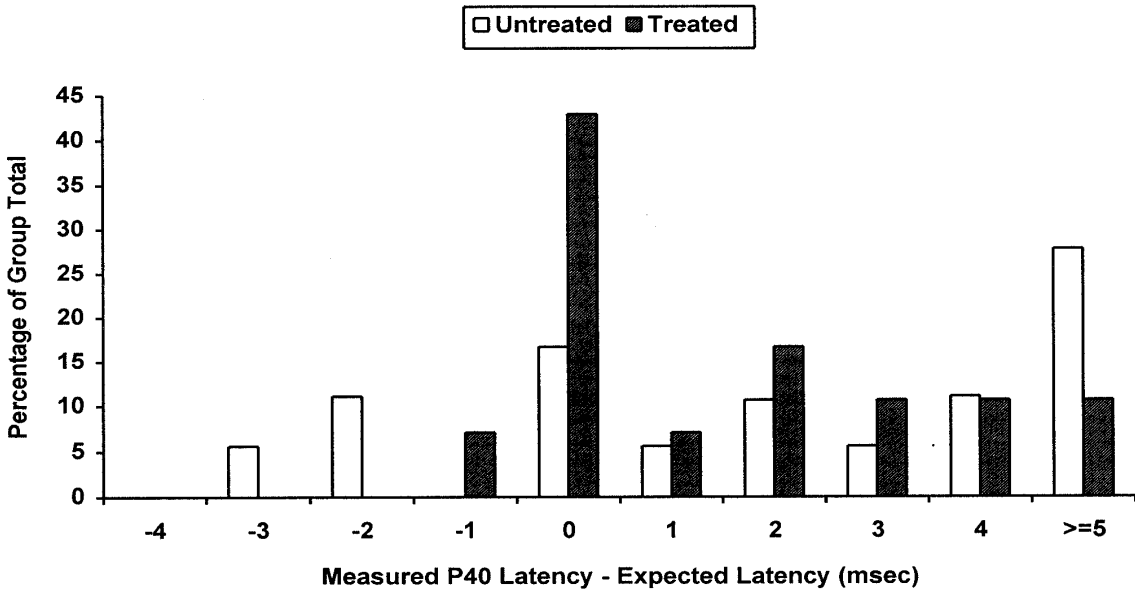

Figure 2 **Measured P40 Relative to Expected Value**

With regard to group comparability, although the actual values are slightly different, there is no change in the findings. There is a higher percentage of divers in the group with history of only treated DCI (Table 17) who have suffered a DCS type 2 (79% compared to 55%).

Table 17
DCI Severity Index

Group	1-4	5-6	8-10
Untreated (n=9)	4(44%)	2(22%)	3(33%)
Treated (n=14)	3(21%)	5(36%)	6(43%)

There is no significant difference between groups (Table 18) with regard to diving history(two-tailed *t* test,df=2 1;*p*>0.05).

Table 18
Diving History

(Mean/Individual)	**Untreated (n=9)**	**Treated (n=14)**
Years Professional Diving	13.6±5.1 (5-22)	14.1±2.9 (8-19)
Career Dives	938±413 (341-1638)	1036±594 (406-2187)
Dives/Year	69±16 (41-91)	71±30 (34-115)
Decompression Days	1021±405 (341-1638)	1156±597 (560-2511)
Decompression Days/Year	75±13 (61-103)	80±28 (43-132)

There is no difference between the groups with regard to alcohol consumption. Table 19 displays the level of alcohol consumption per week for each individual.

Table 19
Individual Alcohol Consumption per Week

Level (units)	Untreated (n=9)	Treated (n=14)
A (1-10)	5(56%)	6(43%)
B (11-20)	2(22%)	4(29%)
C (21-40)	1 (11%)	3(21%)
D (41-80)	1 (11%)	1(7%)

Years Alcohol Consumption -
Untreated (n=9) = 21.4±4.8 (15-3 1) : Treated (n=14) = 20.6±4.5 (16-35)

Average Alcohol Consumption (units/week/individual) -
Untreated (n=9) = 17.1 : Treated (n=14) = 18.1

Previous Higher Level of Alcohol Consumption
Untreated (n=9) = 5 (56%): Treated (n=14) = 9 (64%)

With regard to usage of drugs of abuse, 10 divers (71%) with history of only treated DCI had used drugs of whom 4 had used hard drugs, whereas only 2 divers (22%) with history of untreated DCI had used drugs of abuse.

In response to reports of long-term health problems (Table 20), divers with history of only treated DCI have a greater percentage of reports of irritability.

Table 20
Reports of Long-term Health

	Untreated (n=9)	Treated (n=14)
Concentration	3(33%)	4(29%)
Memory	5(56%)	8(57%)
Irritability	1 (11%)	5(36%)
Depression	2(22%)	3(21%)

5.2.8 Head Injury and Possible Back Injury

Removing subjects from the groups who have reported either a significant head injury, back injury or both, reduces the total numbers in the groups to n=7 for those with history of untreated DCI and n=12 for those with history of only treated DCI.

In the group with history of only treated DCI, the number of abnormal EPs decreases proportionally in comparison to the total group (n=18). In the group with history of untreated DCI, none of those who only reported a back injury had any detected abnormality on EP measurement thus the overall percentage abnormality is

increased (Table 2 1). There is no significant age difference between groups (two-tailed *t* test,df= 1 7;*p*>0.05).

Table 21
Evoked Potential Measurement

		Untreated (n=7)	Treated (n=12)
BAEP	- Subjects	2/6 + IB 332%)	3/12(25%)
	- Measures	2/32 + IB (6%)	6/72 + 1 B (8%)
Median	- Subjects	4/7(57%)	2/12(17%)
	- Measures	7/28(25%)	3/48(6%)
Tibial	- Subjects	5/7(71%)	4/12 + 1B (33%)
	- Measures	10/20(50%)	7/35 + 2B (20%)
Age (years)		38.1±4.7 (34-48)	37.3±4.3 (32-49)

5.3 CLINICAL EXAMINATION

All 31 divers with history of DCI had a clinical examination. Three with history of untreated DCI and 3 with history of only treated DCI had a significant abnormality (Table 22). The abnormalities were in response to examination of sensation, co-ordination and reflexes. In addition, 2 divers with history of untreated DCI had an abnormality of minor significance; in the group with history of only treated DCI, 5 were similarly classified.

Table 22

Group	Significant Abnormality on Clinical Examination	Age
Untreated (n=12)	3(25%)	36.2±5.3 (27-48)
Treated (n= 19)	3(16%)	36.9±3.9 (31-49)
Including abnormalities of minor significance		
Untreated (n=12)	5(42%)	
Treated (n= 19)	8(42%	

5.3.1 Comparison of Abnormalities with regard to Area of Examination

There is little difference between groups in the areas of balance, co-ordination and vestibular examination. With regard to reflexes, the group with history of untreated DCI have a higher percentage abnormal and in the area of sensation, the group with history of only treated DCI have the greater abnormality.

Balance and Co-ordination

Abnormalities (Table 23) were detected in 3 individuals in the group with history of untreated DCI (in 1 case, abnormalities were classified as significant) and 4 in the group with history of only treated DCI (in 2 cases, abnormalities were classified as significant).

Table 23
Abnormality in

Group	Coordination	Balance	Tremor
Untreated (n= 12)	2	2	-
Treated (n= 19)	4	3	1

Sensation

Responses were to light touch/pin prick (LT/PP), two point discrimination (TPD), vibration/proprioception (Vib/Prop) and temperature (Temp). One diver in the group with history of untreated DCI had a minor abnormality and 3 divers in the group with history of only treated DCI had abnormalities, of whom 1 had a significant abnormality (Table 24).

Table 24
Abnormality in

Group	LT/PP	TPD	Vib/Prop	Temp
Untreated (n= 12)	1	-	-	-
Treated (n=19)	2	1	1	1

Reflex Responses

Five divers with history of untreated DCI had abnormal responses; 3 were classified as significant. Three divers with history of only treated DCI had abnormal responses; 1 had a significant abnormality (Table 25).

Table 25
Abnormality in

Group	Absent Ankle Reflex	Asymmetric Reflex
Untreated (n= 12)	2	3
Treated (n= 19)	1	2

Vestibular

Five divers with history of only treated DCI had abnormalities in this area (Table 26). In two cases, hearing loss could be attributed to occupational exposure to noise.

Table 26
Abnormality in

Group	Vision	Hearing
Untreated (n=12)	-	1
Treated (n= 19)	1	5

5.3.2 DCI Severity Index

There is a higher percentage of divers in the group with history of only treated DCI who have suffered a DCS type 2 incident (63% compared to 50%: Table 27).

Table 27
DCS Severity Index

Group	1-4	5-6	8-10
Untreated (n=12)	6(50%)	2(17%)	4(33%)
Treated (n=19)	7(37%)	5(26%)	7(37%)

5.3.3 Diving History

There is no significant difference between groups (Table 28) with regard to diving history(two-tailed *t* test,df=29;$p>0.05$).

Table 28
Diving History

(Mean/Individual)	Untreated (n=12)	Treated (n=19)
Years Professional Diving	11.9±5.3 (5-22)	14.4±3.3 (8-21)
Career Dives	832±414 (315-1638)	1067±582 (406-2184)
Dives/Year	70±15 (41-91)	73±33 (34 -144)
Decompression Days	896±424 (331-1638)	1191±587 (560-2496)
Decompression Days/Year	75±13 (55-103)	82±33 (43-159)

5.3.4 Alcohol Consumption

There is no difference between groups with regard to present level of consumption (Table 29) or years of consumption. The average alcohol consumption for divers with history of only treated DCI is lower, however, this group had a previously higher intake level.

Table 29
Individual Alcohol Consumption per Week

Level (units)	Untreated (n=12)	Treated (n=19)
A (1-10)	5(42%)	10(53%)
B (11-20)	4(33%)	5(26%)
C (21-40)	2(17%)	3(16%)
D (41-80)	1(8%)	1 (5%)

Years Alcohol Consumption -

Untreated (n=12) = 19.5±5.7 (9-3 1): Treated (n=19) = 20.4±4.6 (11-35)

Average Alcohol Consumption (units/week/individual) -

Untreated (n= 12) = 18.08 : Treated (n= 19) = 15.5

Previous Higher Level of Consumption

Untreated (n=12) = 7 (58%): Treated (n=19) = 13 (68%)

5.3.5 Usage of Drugs of Abuse

Fourteen divers (74%) with history of only treated DCI had used drugs of abuse compared to 7 (58%) with history of untreated DCI. This difference is not significant (X^2 test;p>0.05). One diver with history of untreated DCI and 4 divers with history of only treated DCI had used hard drugs.

5.3.6 Subjective Reports of Long-Term Health

The only difference between groups is in response to the question of irritability (Table 30) where divers with history of only treated DCI reported a greater number of problems.

Table 30
Reports of Long-term Health

	Untreated (n=12)	Treated (n=19)
Concentration	3(25%)	5(26%)
Memory	7(58%)	12(63%)
Irritability	1 (8%)	5(26%)
Depression	2(17%)	4(21%)

5.3.7 Head Injury

One diver in the group with history of untreated DCI reported a possible significant head injury. This diver had no detected abnormality on clinical examination. Of the 4 divers in the group with history of only treated DCI, 1 had an abnormality on clinical examination which was classified as significant. Removal of divers with history of significant head injury has very little effect on results (Table 3 1).

Table 31
Significant Abnormality
on Clinical Examination

Group		Age
Untreated (n=1 1)	3(27%)	36.4±5.3 (27-48)
Treated (n=14)	2(14%)	36.9±4.1 (32-49)
Including abnormalities of minor significance		
Untreated (n=1 1)	5(45.5%)	
Treated (n=14)	5(36%)	

5.4 ADDITIONAL REPORTS OF LONG-TERM HEALTH

In addition to reports of problems with concentration, memory, irritability and depression, divers reported other long-term health problems (Table 32). There is very little difference in reports between groups. Only divers with history of treated DCI reported problems with limb weakness and confusion. They also reported a greater percentage of problems with mood swings/personality change.

Table 32

Health Problem	Untreated (n=12)	Treated (n=19)
Musculoskeletal Pain	4(33%)	6(32%)
Limb Weakness	-	2(10.5%)
Headache	4(33%)	4(21%)
Hearing	7(58%)	7(37%)
Vision	1 (8%)	1(5%)
Tiredness	1(8%)	2(10.5%)
Confusion	-	2(10.5%)
RAT	4(33%)	8(42%)
Personality/Mood	1(8%)	5(26%)
Anxiety	1(8%)	1(5%)

6. RESULTS - PRESENCE OF PFO

6.1 NEUROPSYCHOMETRY

6.1.1 Divers with DCI History

In the group of divers with history of DCI, 12 were found to have a PFO and in 17 no PFO was detected. There is no significant difference between groups (two-tailed *t* test,df=27;*p*>0.05). with regard to age, years of education and intellectual ability measured by the NART (Table 33).

Table 33

Factor	With PFO (n=12)	No PFO (n=17)
Age	36.7±2.0 (34-41)	36.8±5.7 (27-49)
Education (yrs)	13.1±2.1 (10-18)	12.3±2.1 (10-16)
NART	116+4.7 (110-124)	114±4.8 (105-123)

On comparison of neuropsychometric test performance (Table 34), divers with PFO had a poorer performance on the Controlled Word Association Test (one-tailed *t* test,df=27;*p*<0.05).

Table 34
Neuropsychometric Test Performance

Test		With PFO (n=12)	No PFO (n=17)
R-OT	- Copy Score	33.4±1.5	33.4±1.7
	- Recall	22.5±5.2	20.1±4.9
	- % Decrement	32.9±14.5	39.9±13.8
LMT	- Recall Score	24.3±5.9	24.1±7.4
	- Delayed Recall	18.6±5.3	19.1±7.6
	- % Decrement	23.9±8.1	22.4±10.6
SDT	- Mean Score	54.9±11.9	54.1±9.6
	- No Attempted	55.3±12.1	55.7±9.5
	- % Correct	99.3±1.4	97.2±4.1
PASAT	- 1 st Trial	36.9±8.4	34.7±7.3
	- 2nd Trial	36.8±8.1	34.0±6.4
	- time/correct response	3.13±0.71	3.33±0.63
SHM	- Mean Score	47.5±8.6	48.2±6.8
	- Percentile	79±22	82±18
	- IQ	115±13	116±11
	- Mean Score	37.9±9.8*	45.4+11.1
CWT	-Percentile	52*	72

* p<0.05

6.1.1.1 DCI Severity Index

A higher percentage of divers with PFO (75%) have suffered type 2 DCS compared to 53% of divers with no detected PFO (Table 35).

Table 35
DCI Severity Index

Group	1-4	5-6	8-10
With PFO (n=12)	3(25%)	3(25%)	6(50%)
No PFO (n= 17)	8(47%)	4(24%)	5(29%)

6.1.1.2 Diving history

There is no significant difference (two-tailed *t* test,df=27;*p*>0.05) between groups with regard to diving history (Table 36).

Table 36
Diving History

(Mean/Individual)	**With PFO (n=12)**	**No PFO (n=17)**
Years Professional Diving	13.3±5.1 (8-23)	14.7±2.9 (10-20)
Career Dives	996±437 (501-1700)	1043±604 (406-2190)
Dives/Year	73±13 (55-89)	68±27 (34-110)
Decompression Days	1044±429 (505-1700)	1179±608 (560-2526)
Decompression Days/Year	77±13 (63-99)	77±26 (43-126)

6.1.1.3 Alcohol Consumption

There is little difference between groups with regard to various measures of alcohol consumption. The weekly level of consumption per individual is shown in Table 37.

Table 37
Individual Alcohol Consumption per Week

Level (units)	**With PFO (n=12)**	**No PFO (n=17)**
A (1-10)	7(58%)	7(41%)
B (11-20)	3(25%)	5(29%)
C (21-40)	2(17%)	3 (18%)
D (41-80)	-	2(12%)

Years of Alcohol Consumption -
With PFO (n=12) = 20±2.4 (17-26): no PFO (n=17) = 20±6.5 (9-35)

Average Alcohol Consumption (units/week/individual) -
With PFO (n=12) = 12.7: no PFO (n=17) = 19.8

Previous Higher Level of Alcohol Consumption -
with PFO (n= 12) = 8 (67%): no PFO (n= 17) = 10 (5 9%)

6.1.1.4 Usage of Drugs of Abuse

There is little difference between groups. Drugs of abuse had been used by 6 divers with PFO (50%) and 10 divers (59%) with no detected PFO. Hard drugs had been used by 4 divers with no detected PFO.

6.1.1.5Subjective Reports of Long-term Health

There is no significant difference between groups (one-tailed *t* test,df=27;p<0.05) with regard to subjective reports of cognitive failures in daily life (**CFQ** - with PFO = 43.7±14.3: no PFO = 44.4±14.4). There is no difference between groups in subjective reports of problems with long-term health (Table 38).

Table 38

Report	With PFO (n=12)	No PFO (n=l 7)
Concentration	4(33%)	4(24%)
Memory	8(67%)	10(59%)
Irritability	3(25%)	5(29%)
Depression	3(25%)	5(29%)

6.1.1.6 Head Injury

Five divers with no detected PFO reported a possible significant head injury. To remove any influence of this factor on results, analysis was carried out in the absence of divers with significant head injury. On comparison of neuropsychometric performance (Table 39), divers with no detected PFO had a poorer performance on Rey-Osterreith Test recall and percentage decrement, percent correct on SDT, time/correct response on PASAT (one-tailed *t* test,df=22;p<0.05) and 2nd Trial of the PASAT (one-tailed *t* test,df=22;p<0.025).

Table 39
Neuropsychometric Test Performance

Test		With PFO (n=12)	No PFO (n=12)
R-OT	- Copy Score	33.4±1.5	33.5±1.5
	- Recall	22.5±5.2	18.8±4.4*
	- % Decrement	32.9±14.5	43.3±12.5*
LMT	- Recall Score	24.3±5.9	24.0±7.9
	- Delayed Recall	18.6±5.3	18.8±8.1
	- % Decrement	23.9±8.1	24.1±11.6
SDT	- Mean Score	54.9±11.9	52.4±9.8
	- No Attempted	55.3±12.1	54.1±9.2
	- % Correct	99.3±1.4	96.8±4.5
PASAT	- 1 st Trial	36.9±8.4	32.0±6.9
	- 2nd Trial	36.8±8.1	31.1±4.9**
	- time/correct response	3.13±0.71	3.59±0.55*
SHM	- Mean Score	47.5±8.6	48.3±6.8
	- Percentile	79±22	82±17
	-IQ	115±13	116±10
CWT	- Mean Score	37.9±9.8	44.5±13.1
	- Percentile	52	67

* $p<0.05$ **$p<0.025$

There is no significant difference between groups (two-tailed *t* test,df=22;$p>0.05$). with regard to age, years of education and intellectual ability measured by the NART (Table 40).

Table 40

Factor	With PFO (n=12)	No PFO (n=12)
Age	36.7±2.0 (34-41)	37.3+6.2 (27-49)
Education (yrs)	13.1±2.1 (10-18)	12.3±2.2 (10-16)
NART	116±4.7 (110-124)	114±4.9 (105-122)

With regard to group comparability, although the actual values are slightly different, there is no change in the findings. There is a slightly higher percentage of divers in the group with PFO (Table 41) who have suffered a DCS type 2 (75% compared to 67%).

Table 41
DCI Severity Index

Group	1-4	5-6	8-10
With PFO (n=12)	3(25%)	3(25%)	6(50%)
No PFO (n= 12)	4(33%)	4(33%)	4(33%)

There is no significant difference between groups (Table 42) with regard to diving history (two-tailed *t* test,df=22;*p*>0.05).

Table 42
Diving History

(Mean/Individual)	With PFO (n=12)	No PFO (n=12)
Years Professional Diving	12.7±3.6 (5-18)	14.4±4.0 (9-22)
Career Dives	966±497 (341-2184)	1008±548 (406-2090)
Dives/Year	75±23 (43-121)	69±28 (34-111)
Decompression Days	1058±543 (341-2496)	1122±510 (560-2158)
Decompression Days/Year	81±23 (59-139)	78±26 (43-117)

There is little difference between the groups with regard to alcohol consumption. Table 43 displays the level of alcohol consumption per week for each individual.

Table 43
Individual Alcohol Consumption per Week

Level (units)	With PFO (n=12)	No PFO (n=12)
A (1-10)	7(58%)	4(33%)
B (11-20)	3(25%)	3(25%)
C (21-40)	2(17%)	3(25%)
D (41-80)	-	2(17%)

Years Alcohol Consumption -
With PFO (n= 12) = 20±2.4 (17-26): No PFO (n= 12) = 20.8±6.9 (9-3 5)

Average Alcohol Consumption (units/week/individual) -
With PFO (n=12) = 12.7: No PFO (n=12) = 23.9

Previous Higher Level of Alcohol Consumption
With PFO (n= 12) = 8 (67%): No PFO (n= 12) = 6 (50%)

With regard to usage of drugs of abuse, 6 divers (50%) from each group had used drugs of abuse although hard drugs had only been used by 4 divers in the group with no detected PFO.

There is no significant difference between groups (one-tailed *t* test,df=22;*p*<0.05) with regard to subjective reports of cognitive failures in daily life (**CFQ** - with PFO = 43.7±14.3: no PFO = 42.6±11. 1). There is no difference between groups in subjective reports of problems with long-term health (Table 44).

Table 44
Reports of Long-term Health

	With PFO (n=12)	No PFO (n=12)
Concentration	4(33%)	3(25%)
Memory	8(67%)	6(50%)
Irritability	3 (25%)	3(25%)
Depression	3(25%)	3(25%)

6.1.1.7 History of Untreated DCI

The neuropsychometric test performance of the groups was reanalysed following removal of individuals with history of untreated DCI. This reduced the total number in each group to n=6 for divers with PFO and n=8 for divers with no detected PFO. On comparison of neuropsychometric performance (Table 45, divers with PFO (n=6) had a poorer performance on the Controlled Word Association Test (one-tailed *t* test,df=12;*p*<0.05). Divers with no PFO (n=8) had a poorer performance on the Rey-Osterreith Test in recall (one-tailed *t* test,df=12;*p*<0.0 1) and also in percentage decrement (*p*<0.025).

Table 45
Neuropsychometric Test Performance

Test		With PFO (n=6)	No PFO (n=8)
R-OT	- Copy Score	34.5±1.1	32.9±2.1
	- Recall	25.7±3.1	20.9±3.3***
	- % Decrement	25.5±9.4	36.7±7.7**
LMT	- Recall Score	26.5±9.4	27.0±7.9
	- Delayed Recall	21.0±4.5	22.1±7.5
	- % Decrement	21.0±8.5	19.0±7.6
SDT	- Mean Score	57.3±13.6	55.1±9.1
	- No Attempted	57.8±14.0	56.5±8.7
	- % Correct	99.3±1.8	97.6+4.5
PASAT	- 1 st Trial	37.7±8.8	32.6±7.5
	- 2nd Trial	38.2±6.9	32.4±5.5
	- time/correct response	3.01±0.60	3.48±0.57
SHM	- Mean Score	54.3±4.1	50.3±6.6
	- Percentile	95±8	87±15
	- IQ	125±7.5	120±10
CWT	- Mean Score	41.2±8.2*	50.5±10.5
	- Percentile	60*	82

* *p*<0.05 ***p*<0.025 ****p*<0.01

There is no significant difference between groups (two-tailed *t* test,df=22;*p*>0.05) with regard to age, years of education and intellectual ability measured by NART (Table 46).

Table 46

Factor	With PFO (n=6)	No PFO (n=8)
Age	36.2±1.9 (34-39)	37.9±5.2 (32-49)
Education (yrs)	13.3±2.4 (11-18)	13.0±2.3 (11-16)
NART	114±4.0 (110-119)	116±4.0 (110-122)

With regard to group comparability, there is little difference between groups. There is a slightly higher percentage of divers in the group with PFO (Table 47) who have suffered a DCS type 2 (83% compared to 75%).

Table 47
DCI Severity Index

Group	1-4	5-6	8-10
With PFO (n=6)	1 (17%)	1(17%)	4(67%)
No PFO (n=8)	2(25%)	4(50%)	2(25%)

There is no significant difference between groups (Table 48) with regard to diving history (two-tailed *t* test,df=12;$p>0.05$).

Table 48
Diving History

(Mean/Individual)	With PFO (n=6)	No PFO (n=8)
Years Professional Diving	13.5±3.3 (8-18)	14.1±2.7 (11-19)
Career Dives	1018±632 (525-2184)	1045±607 (406-2090)
Dives/Year	74±32 (43-121)	72±33 (34-111)
Decompression Days	1173±677 (770-2496)	1145±576 (560-2158)
Decompression Days/Year	85±30 (59-139)	80±32 (43-117)

Table 49 displays the level of alcohol consumption per week for each individual. The group of divers with no PFO have a lower average weekly alcohol consumption.

Table 49
Individual Alcohol Consumption per Week

Level (units)	With PFO (n=6)	No PFO (n=S)
A (1-10)	4(67%)	2(25%)
B (11-20)	1(17%)	3 (38%)
C (21-40)	1(17%)	2(25%)
D (41-80)	-	1(13%)

Years Alcohol Consumption -

With PFO (n=6) = 19±1.5 (17-2 1): No PFO (n=8) = 21.5±5.8 (16-35)

Average Alcohol Consumption (units/week/individual) -

With PFO (n=6) = 11.7: No PFO (n=8) = 22.9

Previous Higher Level of Alcohol Consumption

With PFO (n=6) = 4 (67%): No PFO (n=8) = 6 (75%)

With regard to usage of drugs of abuse, 4 divers (67%) with PFO had used drugs compared to 6 (75%) of divers with no detected PFO. In addition, hard drugs had only been used by 4 divers in the group with no detected PFO.

There is no significant difference between groups (one-tailed *t* test,df=12;*p*<0.05) with regard to subjective reports of cognitive failures in daily life (**CFQ** - with PFO = 43.3±18.8: no PFO = 38.1±8.4). There is no difference between groups in subjective reports of problems with long-term health (Table 50).

Table 50
Reports of Long-term Health

	With PFO (n=6)	**No PFO (n=8)**
Concentration	2(33%)	2(25%)
Memory	4(67%)	4(50%)
Irritability	3(50%)	2(25%)
Depression	1(17%)	2(25%)

6.1.2 Divers with no DCI History

In the group of divers with no DCI history, 5 subjects were found to have a PFO and in 22 subjects no PFO was detected. On comparison of neuropsychometric test performance (Table 5 1), divers with PFO had a poorer performance on the 1st Trial of the PASAT (one-tailed *t* test,df=25;*p*<0.025).

Table 51
Neuropsychometric Test Performance

Test		With PFO (n=5)	No PFO (n=22)
R-OT	- Copy Score	33.2±1.5	33.0±1.9
	- Recall	20.0±5.8	21.6±4.1
	- % Decrement	40.0±16.6	34.7±11.6
LMT	- Recall Score	26.2±5.4	28.4±6.7
	- Delayed Recall	22.8±8.5	24.3±8.2
	- % Decrement	15.6±19.8	16.2±14.9
SDT	- Mean Score	56.2±8.9	53.5±7.3
	- No Attempted	56.2±8.9	54.0±7.1
	- % Correct	100	99.1±1.9
PASAT	- 1 st Trial	32.2±8.9*	39.2±5.7
	- 2nd Trial	33.4±7.0	36.1±7.3
	- time/correct response	3.55±0.93	3.07±0.51
SHM	- Mean Score	47.2±6.7	47.6±6.2
	- Percentile	81±22	80±19
	-IQ	115±10	115±11
CWT	- Mean Score	53.0±11.6	46.6±9.7
	- Percentile	86	75

* $p<0.025$

There is no significant difference between groups (two-tailed *t* test,df=25;$p>0.05$) with regard to age, years of education and intellectual ability as measured by the NART (Table 52).

Table 52

Factor	With PFO (n=5)	No PFO (n=22)
Age	35.6±4.2 (31-42)	36.3±3.5 (30-43)
Education (yrs)	11.2±0.8 (10-12)	11.4±1.9 (8-18)
NART	117±4.5 (112-122)	113±6.0 (100-124)

6.1.2.1 Diving history

There is no significant difference between groups (two-tailed *t* test, df=25;$p>0.05$) with regard to diving history. Divers with PFO have a more extensive diving history (Table 53).

Table 53
Diving History

(Mean/Individual)	With PFO (n=5)	No PFO (n=22)
Years Professional Diving	13.2±4.5 (8-18)	14.5±4.8 (9-26)
Career Dives	1166±872 (444-2155)	728±359 (245-1802)
Dives/Year	87±50 (25-149)	55±31 (12-137)
Decompression Days	1265±888 (520-2375)	836±363 (470-2010)
Decompression Days/Year	95±49 (29-149)	62±30 (28-144)

6.1.2.2 Alcohol Consumption

There is little difference between groups with regard to various measures of alcohol consumption. The level of individual alcohol consumption per week is shown in Table 54.

Table 54
Individual Alcohol Consumption per Week

Level (units)	With PFO (n=5)	No PFO (n=22)
A (1-10)	1(20%)	7(32%)
B (11-20)	1(20%)	6(27%)
C (21-40)	2(40%)	6(27%)
D (41-80)	1(20%)	3(14%)

Years Alcohol Consumption -
With PFO (n=5) = 18.6±4.1 (15-24): no PFO (n=22) = 19±4.1 (8-25)

Average Alcohol Consumption (units/week/individual) -
With PFO (n=5) = 29.0: no PFO (n=22) = 23.0

Previous Higher Level of Alcohol Consumption -
With PFO (n=5) = 3 (60%): no PFO (n=22) = 12 (55%)

6.1.2.3 Usage of Drugs of Abuse

In the group of divers with PFO 1 (20%) had used drugs of abuse compared to 8 (36%) in the group of divers with no detected PFO.

6.1.2.4 Subjective Reports of Long-term Health

There is no significant difference between groups with regard to subjective reports of cognitive failures in daily life (**CFQ** - with PFO (n=5) = 38.6±8.9 : no P170 (n=22) = 43.6±10.5). Regarding reports of long-term health (Table 55), divers with P170 did not report any problems with concentration and divers with no PFO had a lower percentage of reports of problems with depression.

Table 55
Reports of Long-term Health

	With PFO (n=5)	No PFO (n=22)
Concentration	-	7(32%)
Memory	2(40%)	13(59%)
Irritability	1 (20%)	4(18%)
Depression	2(40%)	2(9%)

6.1.2.5 Head Injury

The group with no detected PFO includes 4 divers who reported a possible significant head injury whereas in the group with PFO, no subjects had reported significant head injury. On comparison of neuropsychometric test performance in the absence of the divers with significant head injury (Table 56), divers with PFO again had a poorer performance on the 1st Trial of the PASAT (one-tailed *t* test,df=2I; $p<0.05$).

Table 56
Neuropsychometric Test Performance

Test		With PFO (n=5)	No PFO (n=18)
R-OT	- Copy Score	33.2±1.5	33.2±1.9
	- Recall	20.0±5.8	21.1±3.7
	- % Decrement	40.0±16.6	36.3±10.3
LMT	- Recall Score	26.2±5.4	27.8±5.7
	- Delayed Recall	22.8±8.5	23.4±7.8
	- % Decrement	15.6±19.8	18.1±15.7
SDT	- Mean Score	56.2±8.9	52.4±7.3
	- No Attempted	56.2±8.9	52.9±7.2
	- % Correct	100	99.0±2.0
PASAT	- 1 st Trial	32.2±8.9*	38.6±5.8
	- 2nd Trial	33.4±7.0	35.8±7.5
	- time/correct response	3.55±0.93	3.12±0.53
SHM	- Mean Score	47.2±6.7	47.8±6.4
	- Percentile	81±22	81±18
	- IQ	115±10	116±11
CWT	- Mean Score	53.0±11.6	45.8±8.8
	- Percentile	86	74

* $p<0.05$

There is no significant difference between groups (Table 57) with regard to age, years of education and intellectual ability measured by the NART (two-tailed *t* test,df=2I;$p>0.05$).

Table 57

Factor	With PFO (n=5)	No PFO (n=18)
Age	35.6±4.2 (31-42)	36.3±3.5 (30-43)
Education (yrs)	11.2±0.8 (10-12)	11.6±2.0 (10-18)
NART	117±4.5 (112-122)	113±6.0 (100-124)

However, the groups were found to be significantly different with regard to diving history (two-tailed *t* test,df=21,$p<0.05$) with regard to dives per year and decompressions per year. Divers with PFO having the more extensive diving history (Table 58).

Table 58
Diving History

(Mean/Individual)	With PFO (n=5)	No PFO (n=18)
Years Professional Diving	13.2±4.5 (8-18)	15.1±5.1 (9-26)
Career Dives	1166±872 (444-2155)	693±359 (245-1802)
Dives/Year	87±50 (25-149)	48±26 (12-129)*
Decompression Days	1265±888 (520-2375)	802±380 (470-2010)
Decompression Days/Year	95±49 (29-149)	56±26 (28-144)*

* $p<0.05$

6.1.3 Age-Matched Pairs

Divers both with and without history of DCI were matched with regard to age within 2 years, years of education, NART, diving history, history of untreated DCI and DCI history. Divers with significant head injury were not included. A total of 13 pairs could be matched for comparison on neuropsychometric test performance. There is no significant difference between divers with PFO and divers with no PFO on any test (Table 59).

Table 59
Neuropsychometric Test Performance

Test		With PFO (n=13)	No PFO (n=13)
R-OT	- Copy Score	33.9±1.3	33.1±2.0
	- Recall	22.4±5.5	20.6±4.3
	- % Decrement	34.1±15.5	37.8±11.7
LMT	- Recall Score	24.8±5.7	26.5±8.2
	- Delayed Recall	20.2±7.0	20.9±8.7
	- % Decrement	20.0+13.4	23.7±13.5
SDT	- Mean Score	55.7±10.9	55.1±7.7
	- No Attempted	56.0±11.0	56.2±7.6
	- % Correct	99.5±1.3	98.1±3.6
PASAT	- 1 st Trial	35.2±8.5	36.1±8.3
	- 2nd Trial	36.0±7.4	34.8±8.0
	- time/correct response	3.25±0.76	3.29±0.69
SHM	- Mean Score	48.9±8.1	49.2±7.6
	- Percentile	82±23	82±21
	- IQ	117±12	117±12
CWT	- Mean Score	46.4±10.4	46.5±11.1
	- Percentile	73	71

There is no significant difference between groups (two-tailed *t* test,df=25;*p*>0.05) with regard to age, years of education and intellectual ability as measured by the NART (Table 60).

Table 60

Factor	With PFO (n=13)	No PFO (n=13)
Age	35.9±2.8 (31-42)	35.6±3.1 (30-40)
Education (yrs)	12.2±2.0 (10-18)	11.9±2.3 (10-18)
NART	115±4 (110-122)	115±5 (105-124)

6.1.3.1 DCI Severity Index

Eight divers from each group had a history of DCI. Six divers (75%) from each group had suffered a DCS type 2 (Table 61).

Table 61
DCI Severity Index

Group	1-4	5-6	8-10
With PFO (n=8)	2(25%)	1(12.5%)	5(62.5%)
No PFO (n=8)	2(25%)	4(50%)	2(25%)

6.1.3.2 Diving history

There is no significant difference between groups (two-tailed *t* test, df=25;*p*>0.05) with regard to diving history (Table 62).

Table 62
Diving History

(Mean/Individual)	With PFO (n=13)	No PFO (n=13)
Years Professional Diving	13.7±3.5 (8-18)	13.6±3.6 (9-2 1)
Career Dives	1105±657 (444-2184)	864±464 (406-1802)
Dives/Year	80±37 (25-149)	64±31 (34-129)
Decompression Days	1216±678 (520-2496)	994±473 (470-2010)
Decompression Days/Year	88±36 (29-149)	74±32 (37-144)

6.1.3.3 Alcohol Consumption

There is little difference between groups with regard to various measures of alcohol consumption. The level of individual alcohol consumption per week is shown in Table 63.

Table 63
Individual Alcohol Consumption per Week

Level (units)	With PFO (n=13)	No PFO (n=13)
A (1-10)	5(39%)	5(39%)
B (11-20)	4(31%)	3(23%)
C (21-40)	3(23%)	3(23%)
D (41-80)	1(8%)	2(15%)

Years Alcohol Consumption -
With PFO (n=13) = 19.2+2.6 (15-24): no PFO (n=13) = 19.1±3.1 (13-235)

Average Alcohol Consumption (units/week/individual) -
With PFO (n= 13) = 19.1 : no PFO (n= 13) = 22.5

Previous Higher Level of Alcohol Consumption -
With PFO (n= 13) = 9 (69%): no PFO (n= 13) = 5 (3 9%)

6.1.3.4 Usage of Drugs of Abuse

Six divers (46%) from each group had used drugs of abuse. Hard drugs had only been used by 3 divers from the group with no detected PFO.

6.1.3.5 Subjective Reports of Long-term Health

There is no significant difference between groups with regard to subjective reports of cognitive failures in daily life (**CFQ** - with PFO = 41.3±14.0 : no PFO = 44.9±9.9).

Regarding reports of long-term health (Table 64), there is very little difference between groups.

Table 64
Reports of Long-term Health

	With PFO (n=13)	No PFO (n=13)
Concentration	5(39%)	5(39%)
Memory	4(31%)	3(23%)
Irritability	3(23%)	3(23%)
Depression	1(8%)	2(15%)

6.2 MGL of HMPAO-SPECT BRAIN IMAGE

6.2.1 Divers with DCI History

Of the 12 divers with DCI history who were found to have a PFO, texture analysis of HMPAO-SPECT brain image could be determined in 9 cases. MGL of HMPAO-SPECT brain image could be determined in 13 of the 17 divers in whom no PFO was detected. There is no significant difference (one-tailed *t* test,df=20;$p>0.05$) between groups with regard to MGL (Table 65). Divers with PFO have the lower value. Similarly, there is no significant difference in age between groups (two-tailed *t* test,df=20;$p>0.05$).

Table 65
MGL of HMPAO-SPECT Brain Image

Group	MGL	Age
With PFO (n=9)	5.77±0.60 (4.45-6.51)	38.1±2.5 (34-42)
No PFO (n= 13)	6.14±0.96 (4.11-7.71)	37.1±6.6 (26-50)

6.2.1.1 DCI Severity Index

There is no difference between groups (Table 66).

Table 66
DCI Severity Index

Group	1-4	5-6	8-10
With PFO (n=9)	3(33%)	2(22%)	4(44%)
No PFO (n=13)	5(38%)	4(31%)	4(31%)

6.2.1.2 Diving History

Table 67 shows the diving history of the groups expressed as the mean per individual. There is no significant difference between groups with regard to diving history (two-tailed *t*-test,df=20;$p>0.05$).

Table 67
Diving History

(Mean/Individual)	With PFO (n=9)	No PFO (n=13)
Years Professional Diving	15.0±2.5 (11-20)	13.6±4.5 (8-23)
Career Dives	1097±526 (540-2190)	977±562 (406-2110)
Dives/Year	71±24 (41-110)	69±23 (34-106)
Decompression Days	1231±556 (690-2526)	1060±544 (505-2178)
Decompression Days/Year	80±22 (57-126)	75±22 (43-109)

6.2.1.3 Alcohol Consumption

There is little difference between groups with regard to alcohol consumption. Divers with PFO have a lower weekly consumption, however, a greater number of these divers had consumed alcohol at a previous higher level. The individual level of alcohol consumption is shown in Table 68.

Table 68
individual Alcohol Consumption per Week

Level (units)	With PFO (n=9)	No PFO (n=13)
A (1-10)	4(44%)	5(38%)
B (11-20)	3(33%)	3(23%)
C (21-40)	2(22%)	3(23%)
D (41-80)	-	2(15%)

Years Alcohol Consumption -
With PFO (n=9) = 21.4+3.0 (17-27): No PFO (n=13) = 20.3±7.5 (8-36)

Average Alcohol Consumption (units/week/individual) -
With PFO (n=9) = 14.9: No PFO (n= 13) = 22.5

Previous Higher Level of Consumption
With PFO (n=9) = 6 (67%): No PFO (n=13) = 7 (54%)

6.2.1.4 Usage of Drugs of Abuse

Five divers (56%) with PFO had used drugs of abuse compared to 8 (62%) of divers with no detected PFO. Hard drugs had been used by 4 divers in the group with no detected PFO.

6.2.1.5 Subjective Reports of Long -Term Health

There is little difference between groups in response to problems with long-term health (Table 69).

Table 69
Reports of Long-term Health

	With PFO (n=9)	No PFO (n=13)
Concentration	2(22%)	2(15%)
Memory	5(56%)	7(54%)
Irritability	2(22%)	3(23%)
Depression	1 (11%)	3(23%)

6.2.1.6 Head Injury

Two divers in the group with no detected PFO had reported a possible significant head injury. On removing these two divers from the analysis, there is no significant difference between groups (one-tailed *t* test,df=18;*p*>0.05) with regard to MGL. Divers with PFO have a lower MGL (Table 70). There is no significant age difference between groups (two-tailed *t* test,df=18;*p*>0.05).

Table 70
MGL of Divers with no Significant Head Injury

Group	MGL	Age
With PFO (n=9)	5.77±0.60 (4.45-6.51)	38.1±2.5 (34-42)
No P170 (n= 11)	6.17±1.05 (4.11-7.71)	38.0±6.8 (26-50)

With regard to group comparability, although the actual values are slightly different, there is no change in the findings. A similar percentage of divers in each group (Table 71) have suffered a DCS type 2 (with PFO = 66% compared to no PFO = 63%).

Table 71
DCI Severity Index

Group	1-4	5-6	8-10
With PFO (n=9)	3(33%)	2(22%)	4(44%)
No PFO (n= 11)	4(36%)	4(36%)	3(27%)

There is no significant difference between groups (Table 72) with regard to diving history (two-tailed *t* test,df=18;*p*>0.05).

Table 72
Diving History

(Mean/Individual)	With PFO (n=9)	No PFO (n=l 1)
Years Professional Diving	15.0±2.5 (11-20)	14.5±4.3 (8-23)
Career Dives	1097±526 (540-2190)	1049±584 (406-2110)
Dives/Year	71±24 (41-110)	70±25 (34-106)
Decompression Days	1231±556 (690-2526)	1147±548 (560-2178)
Decompression Days/Year	80±22 (57-126)	77±23 (45-109)

With regard to alcohol consumption, divers with PFO have a lower weekly average consumption but a higher percentage of this group had previously consumed alcohol at a higher level. Table 73 displays the level of alcohol consumption per week.

Table 73
Individual Alcohol Consumption per Week

Level (units)	With PFO (n=9)	No PFO (n=11)
A (1-10)	4(44%)	4(36%)
B (11-20)	3(33%)	2(18%)
C (21-40)	2(22%)	3(27%)
D (41-80)	-	2(18%)

Years Alcohol Consumption -

With P170 (n=9) = 21.4±3.0 (17-27): No P170 (n= 11) = 21.5±7.5 (8-3 6)

Average Alcohol Consumption (units/week/individual) -

With PFO (n=9) = 14.9: No PFO (n=11) = 24.8

Previous Higher Level of Consumption

With PFO (n=9) = 6 (67%): No PFO (n=11) = 5 (46%)

With regard to usage of drugs of abuse, 5 divers (56%) with PFO and 6 (55%) divers with no PFO had used drugs of abuse. Hard drugs had only been used by 4 divers in the group with no detected PFO.

There is no difference between groups in subjective reports of problems with long-term health (Table 74).

Table 74
Reports of Long-term Health

	With PFO (n=9)	No PFO (n=11)
Concentration	2(22%)	2(18%)
Memory	5(56%)	5(45%)
Irritability	2(22%)	2(18%)
Depression	1 (11%)	2(18%)

6.2.2 Divers with no DCI History

Of the 5 divers with no DCI history who were found to have a PFO, texture analysis of HMPAO-SPECT brain image could be determined in only 2 cases. MGL of HMPAO-SPECT brain image could be determined in 17 of the 22 divers in whom no PFO was detected. There is no significant difference (one-tailed *t* test,df=15;$p>0.05$) between groups with regard to MGL (Table 75). Similarly, there is no significant difference in age between groups (two-tailed *t* test,df=15;$p>0.05$) However, the validity of the comparison is in doubt when one group contains only 2 members.

Table 75
MGL of HMPAO-SPECT Brain Image

Group	MGL	Age
With PFO (n=2)	7.58±1.14 (6.77-8.38)	31.5±0.7 (31-32)
No PFO (n=17)	6.50±0.91(4.11-8.17)	36.7±3.5 (30-43)

6.2.3 Age-Matched Pairs

Divers both with and without DCI history were matched with regard to age within 2 years, DCI and diving history. Divers with a head injury classified as significant were not included. A total of 9 pairs could be matched for analysis of the effect of presence of PFO on NIGL of HMPAO-SPECT brain image (Table 76). There is no significant difference between groups with regard to NIGL of HMPAO-SPECT brain image and age (*t* test,df=8;*p*>0.05).

Table 76
MGL of HMPAO-SPECT Brain Image

Group	MGL	Age
With PFO (n=9)	6.12±1.08 (4.45-8.38)	36.0±3.1 (31-40)
No PFO (n=9)	6.05±1.05 (4.11-7.71)	35.9±2.8 (31-39)

6.2.3.1 DCI Severity Index

Of the 9 pairs, 7 have a DCI history. In the groups of divers with PFO, 5 have suffered a DCS type 2 compared to 4 in the group with no detected PFO (Table 77).

Table 77
DCI Severity Index

Group	1-4	5-6	8-10
With PFO (n=7)	2(29%)	2(29%)	3(43%)
No PFO (n=7)	3(43%)	3(43%)	1(14%)

6.2.3.2 Diving History

Table 78 shows the diving history of the groups. There is no significant difference between groups with regard to diving history (two-tailed *t*-test,df=8;*p*>0.05).

Table 78
Diving History

(Mean/Individual)	With PFO (n=9)	No PFO (n=9)
Years Professional Diving	13.0±3.3 (7-16)	12.8±2.6 (9-17)
Career Dives	846±353 (500-1429)	783±467 (406-1800)
Dives/Year	65±17 (41-89)	59±24 (34-106)
Decompression Days	942±293 (585-1429)	881±452 (470-1800)
Decompression Days/Year	73±12 (57-89)	67±24 (43-106)

6.2.3.3 Alcohol Consumption

There is little difference between groups with regard to alcohol consumption. The individual level of alcohol consumption per week is shown in Table 79.

Table 79
Individual Alcohol Consumption per Week

Level (units)	With PFO (n=9)	No PFO (n=9)
A (1-10)	2(22%)	3(33%)
B (11-20)	4(44%)	1 (11%)
C (21-40)	2(22%)	2(22%)
D (41-80)	1 (11%)	3(33%)

Years Alcohol Consumption -
With PFO (n=9) = 19.3±3.3 (15-24): No PFO (n=9) = 18.7±4.4 (9-23)

Average Alcohol Consumption (units/week/individual) -
With PFO (n=9) = 22.1 : No PFO (n=9) = 21.0

Previous Higher Level of Consumption
With PFO (n=9) = 7 (78%): No PFO (n=9) = 5 (56%)

6.2.3.4 Usage of Drugs of Abuse

Three divers (33%) with PFO had used drugs of abuse compared to 7 (78%) of divers with no detected PFO. Hard drugs had been used by 3 divers with no detected PFO.

6.2.3.5 Subjective Reports of Long -Terin Health

The total numbers are small. Divers with PFO reported more problems with irritability and depression and fewer problems with concentration (Table 80).

Table 80
Reports of Long-term Health

	With PFO (n=9)	No PFO (n--9)
Concentration	1 (11%)	3(33%)
Memory	4(44%)	4(44%)
Irritability	3(33%)	1 (11%)
Depression	2(22%)	1 (11%)

6.3 NEUROPHYSIOLOGY

6.3.1 Divers with DCI History

In 28 divers with DCI history (12 with PFO, 16 no detected PFO) a comparison could be made between presence of PFO and evoked potential measurement. There are insufficient total numbers in the results of the BAEP and Median SSEP per individual for valid statistical analysis (Table 81). There is no significant difference between groups (X^2 test;p>0.05) with regard to abnormal Median SSEP measurements or Tibial SEP measurement. Divers with no PFO have a higher percentage abnormal BAER There is no significant difference in age between groups (two-tailed t test,df=26;p>0.05).

Table 81
Evoked Potential Measurement

		With PFO (n=12)	No PFO (n=16)
BAEP	- Subjects	1/12 + lB (8%)	6/15(40%)
	- Measures	1/72 + lB (1%)	9/86 + lB (10.5%)
Median	- Subjects	5/12(42%)	4/16(25%)
	- Measures	5/48(10%)	8/62(13%)
Tibial	- Subjects	5/12(42%)	8/16 + 1 B (50%)
	- Measures	9/36 + 1 B (25%)	15/45 + lB (33%)
Age (years)		36.7±2.2 (34-41)	37.5±5.3 (31-49)
	- n=15		37.4±5.4 (31-49)

6.3.1.1 Distribution of Measured P40 Latency Relative to Expected Value

On comparison of Tibial SEP expected P40 with measured P40 (Figure '3), both groups have a similar percentage of measured P40 values which are lower (ie faster) than expected (with PFO = 17%: no PFO = 12.5%). Divers with no PFO have a higher percentage which are longer than the ULN (41% compared to 21%). This value is not significantly higher (X^2 test;p>0.05).

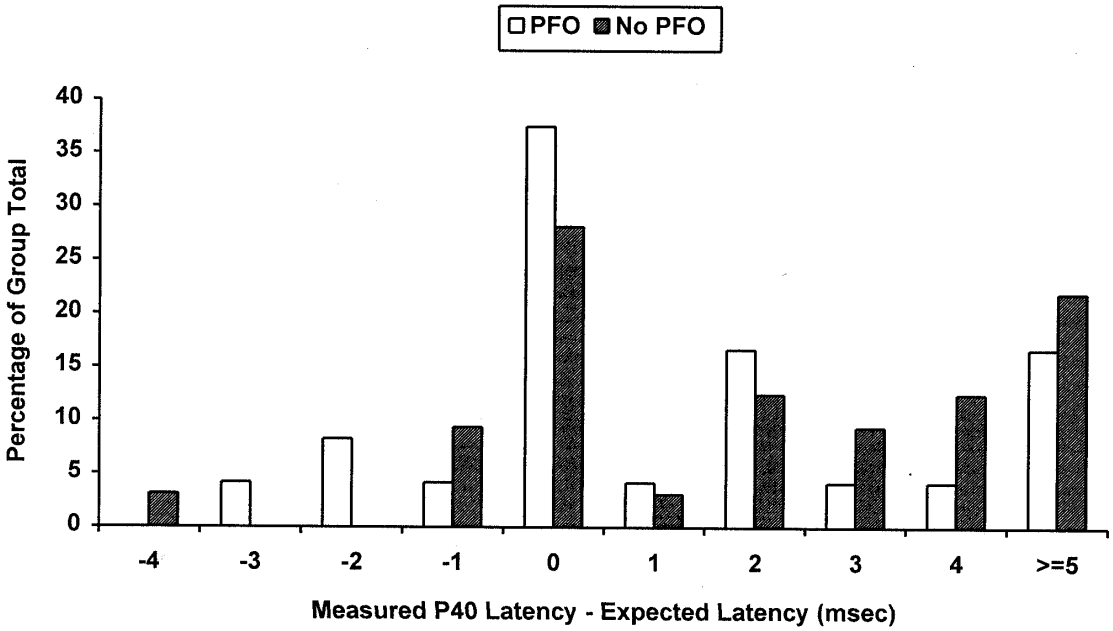

Figure 3 **Measured P40 Latency Relative to Expected Value**

6.3.1.2 DCI Severity Index

There is a higher percentage of divers with PFO (Table 82) who have suffered a DCS type 2 incident (75% compared to 50%).

Table 82
DCI Severity Index

Group	1-4	5-6	8-10
With PFO (n=12)	3(25%)	3(25%)	6(50%)
No PFO(n= 16)	8(50%)	4(25%)	4(25%)

6.3.1.3 Diving History

Table 83 displays the diving history of the groups. There is no significant difference between groups with regard to diving history (two-tailed *t* test;df=26;p>0.05).

Table 83
Diving History

(Mean/Individual)	With PFO (n=12)	No PFO (n=16)
Years Professional Diving	12.8+3.7 (5-19)	14.6±4.3 (6-22)
Career Dives	965±498 (341-2187)	1011±574 (406-2090)
Dives/Year	74+22 (43-115)	69±32 (34-144)
Decompression Days	1058±548 (341-2511)	1133±558 (454-2220)
Decompression Days/Year	81±22 (59-132)	78±31 (43-159)

6.3.1.4 Alcohol Consumption

There is no difference between the groups with regard to alcohol consumption. The level of alcohol consumption per week for each individual is shown in Table 84.

Table 84
Individual Alcohol Consumption per Week

Level (units)	With PFO (n=12)	No PFO (n=16)
A (1-10)	7(58%)	7(44%)
B (11-20)	3(25%)	5 (31%)
C (21-40)	2(17%)	2(13%)
D (41-80)	-	2(13%)

Years Alcohol Consumption -
With PFO (n=12) = 20.0±2.6(17-26): No PFO (n=16) = 20.9±6.0(11-35)

Average Alcohol Consumption (units/week/individual) -
With PFO (n=12) = 12.7: No PFO (n=16) = 19.1

Previous Higher Level of Alcohol Consumption -
With PFO (n=l 2) = 8 (67%): No PFO (n= 16) = 10 (63%)

6.3.1.5 Usage of Drugs of Abuse

Six divers (50%) with PFO have used drugs of abuse compared to 10 (63%) with no PFO. Hard drugs had been used by 4 divers with no detected PFO.

6.3.1.6 Subjective Reports of Long -Term Health

There is very little difference between groups with regard to subjective reports of problems with long-term health (Table 85).

Table 85
Reports of Long-term Health

	With PFO (n=12)	No PFO (n=16)
Concentration	4(33%)	4(25%)
Memory	8(67%)	9(56%)
Irritability	3(25%)	5(31%)
Depression	3(25%)	5(31%)

6.3.1.7 Head Injury

Five subjects in the group with no PFO reported a head injury which was classified as significant. On removal of these subjects from the analysis, there is very little change in results (Table 86). There is no significant age difference between groups (two-tailed *t* test,df=21;*p*>0.05).

Table 86
Evoked Potential Measurement

		With PFO (n=12)	No PFO (n=11)
BAEP	- Subjects	1/12 + 1B (8%)	4/10(40%)
	- Measures	1/72 + 1B (1%)	7/56 (12.5%)
Median	- Subjects	5/12(42%)	4/11(36%)
	- Measures	5/48(10%)	8/42(19%)
Tibial	- Subjects	5/12(42%)	5111 + 1B (45%)
	- Measures	9/36 + 1B (25%)	10/31 + 1B (32%)
Age (years)		36.7±2.2 (34-41)	38.4±5.5 (32-49)

The group total numbers are too small for valid statistical analysis apart from total measures on the Tibial SEP Median and SSEP where no significant difference was found (X^2 test;*p*>0.05). The number of abnormalities detected following Median stimulation for the group with no PFO has not altered on removal of divers with head injury, thus the percentage abnormal has increased. There is a proportional decrease in the abnormalities detected following BAEP and Tibial stimulation.

On comparison of Tibial SEP expected P40 with measured P40 (Figure 4), divers with PFO have a higher percentage of measured P40 values which are lower (ie faster) than expected (17% cf 4.5%). Divers with no PFO have a higher percentage which are longer than the ULN (46%) compared to divers with PFO (2 1 %). This difference is not significant (X^2,*p*>0.05).

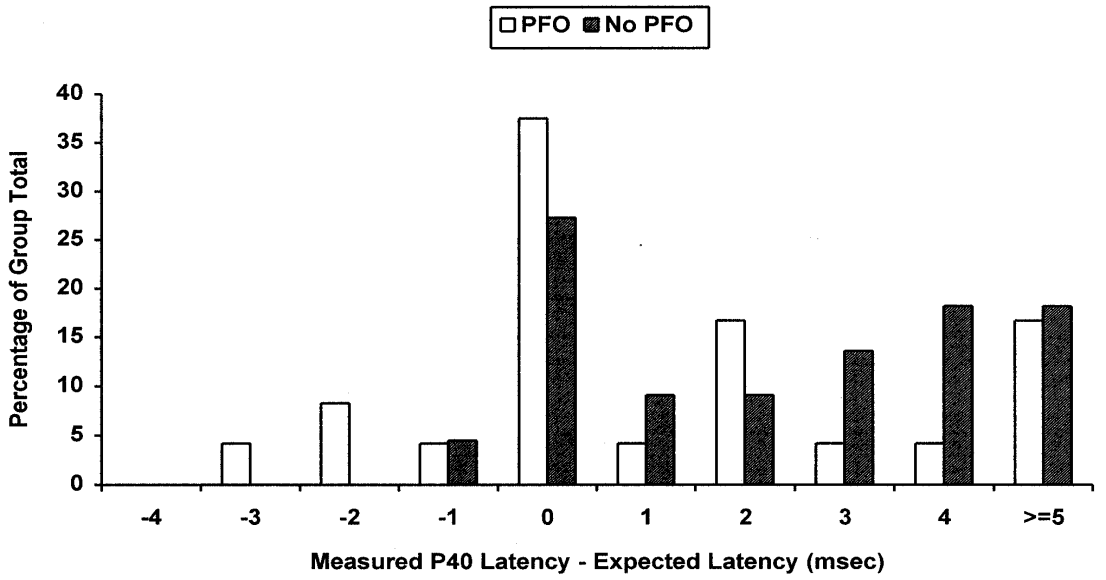

Figure 4 **Measured P40 Relative to Expected Value**

With regard to group comparability, although the actual values are slightly different, there is no change in the findings. A higher percentage of divers with PFO (Table 87) have suffered a DCS type 2 (with PFO = 75% compared to no PFO = 63%).

Table 87
DCI Severity Index

Group	1-4	5-6	8-10
With PFO (n=12)	3(25%)	3(25%)	6(50%)
No PFO (n=11)	4(36%)	4(36%)	3(27%)

There is no significant difference between groups (Table 88) with regard to diving history (two-tailed *t* test,df=21;*p*>0.05).

Table 88
Diving History

(Mean/Individual)	**With PFO (n=12)**	**No PFO (n=16)**
Years Professional Diving	12.8±3.7 (5-19)	15.1±3.7 (10-22)
Career Dives	965±498 (341-2187)	1033±569 (406-2090)
Dives/Year	74±22 (43-115)	66±28 (34-111)
Decompression Days	1058±548 (341-2511)	1162±522 (560-2158)
Decompression Days/Year	81±22 (59-132)	76±25 (43-114)

With regard to alcohol consumption, divers with PFO have a lower weekly average consumption but a higher percentage of this group had previously consumed alcohol at a higher level. Table 89 displays the level of alcohol consumption per week.

Table 89
Individual Alcohol Consumption per Week

Level (units)	With PFO (n=12)	No PFO (n=11)
A (1-10)	7(58%)	4(36%)
B (11-20)	3(25%)	3(27%)
C (21-40)	2(17%)	2(18%)
D (41-80)	-	2(18%)

Years Alcohol Consumption -

With PFO (n= 12) = 20.0±2.6 (17-26): No PFO (n= 11) = 22.1±6.0 (15 -3 5)

Average Alcohol Consumption (units/week/individual) -

With PFO (n=12) = 12.7: No PFO (n=11) = 23.3

Previous Higher Level of Consumption

With PFO (n=12) = 8(67%) : No PFO (n=11) = 6(55%)

With regard to usage of drugs of abuse, 6 divers (50%) with PFO and 6 (55%) divers with no PFO had used drugs of abuse. Hard drugs had only been used by 4 divers in the group with no detected PFO.

There is no difference between groups in subjective reports of problems with long-term health (Table 89).

Table 89
Reports of Long-term Health

	With PFO (n=12)	No PFO (n=11)
Concentration	4(33%)	3(27%)
Memory	8(67%)	5(45%)
Irritability	3(25%)	3(27%)
Depression	3(25%)	3(27%)

6.3.1.8 Head Injury and Possible Back Injury

Three divers with PFO and 6 with no detected PFO reported a significant head injury and/or back injury. This reduces the group totals to n=9 for divers with PFO and n=10 for those with no detected PFO. There is no significant difference in age between groups (two tailed *t* test,df=17;$p>0.05$).

In the group with PFO (Table 90), the number of abnormalities detected following BAEP and Tibial SEP stimulation is unchanged on removal of divers with head and/or back injury, therefore the percentage abnormal has increased. In the group with no PFO, the percentage abnormal changes only slightly. There are insufficient total numbers for valid statistical analysis.

Table 90
Evoked Potential Measurement

	With PFO (n=9)	No PFO (n=10)
BAEP - Subjects	1/9 + 1B (11%)	4/9(44%)
- Measures	1/54 + 1B (2%)	7/50(14%)
Median - Subjects	3/9(33%)	3/10(30%)
- Measures	3/36(8%)	7/40 (17.5%)
Tibial - Subjects	5/9(56%)	4/10 + 1B (40%)
- Measures	9/27 + 1B (25%)	8/28 + 1B (29%)
Age (years)	36.7±1.7 (34-40)	38.4±5.8 (32-49)
- n=9		38.3±6.1 (32-49)

6.3.2 Divers with no DCI History

Five divers with PFO in the group with no DCI history were compared to 22 divers with no detected PFO with regard to abnormality of evoked potential measurement (Table 91). There would seem to be an increase in abnormal responses in divers with PFO on BAEP and Median SSEP measurement. However, the total numbers are too small for valid statistical analysis or conclusions to be made.

Table 91
Evoked Potential Measurement

	With PFO (n=5)	No PFO (n=22)
BAEP - Subjects	115 + 1 B (20%)	2/22(9%)
- Measures	3/30 + IB (10%)	4/132(3%)
Median - Subjects	3/5(60%)	2/22(9%)
- Measures	3/20(15%)	2/86(2%)
Tibial - Subjects	1/5(20%)	4/22 + 1B (18%)
- Measures	2/15(13%)	4/66 + 1B (6%)
Age (years)	35.6+4.2 (31-42)	36.3+3.5 (30-43)

The comparability of the groups with and without PFO are as stated in Sections 6.1.2.1 -6.1.2.4.

6.3.3 Age-Matched Pairs

Divers both with and without PFO were matched with respect to age within 2 years, DCI and diving history. Thirteen pairs were matched (8 with DCI history and 5 with no DCI history). On comparison of evoked potential response (Table 92), divers with PFO have a slightly higher percentage of individuals with abnormal Median SSEP whereas divers with no detected PFO have a higher percentage of abnormal BAER There are insufficient total numbers in the groups for valid statistical analysis apart

from total Tibial SEP measurement where no significant difference is found (X^2, p>0.05).

Table 92
Evoked Potential Measurement

	With PFO (n=13)	No PFO (n=13)
BAEP - Subjects	2/13 + 1B (15%)	3/13 (23%)
- Measures	4/78 + 1B (5%)	6/78(8%)
Median - Subjects	6/13(46%)	4/13(31%)
- Measures	6/52 (11.5%)	6/48 (12.5%)
Tibial - Subjects	5/13 (38.5%)	4/13 + 1B (31%)
- Measures	9/39(23%)	6/39 + 1B (15%)
Age (years)	35.9±2.7 (31-42)	35.7±2.9 (30-40)

6.3.3.1 Distribution of Measured P40 Latency Relative to Expected Value

On comparison of Tibial SEP expected P40 with measured P40 (Figure 5), divers with no detected PFO have a higher percentage of measured P40 values which are lower (ie faster) than expected (with PFO = 8% : no PFO = 15%). The groups have a similar percentage which are longer than the ULN (23% compared to 19%).

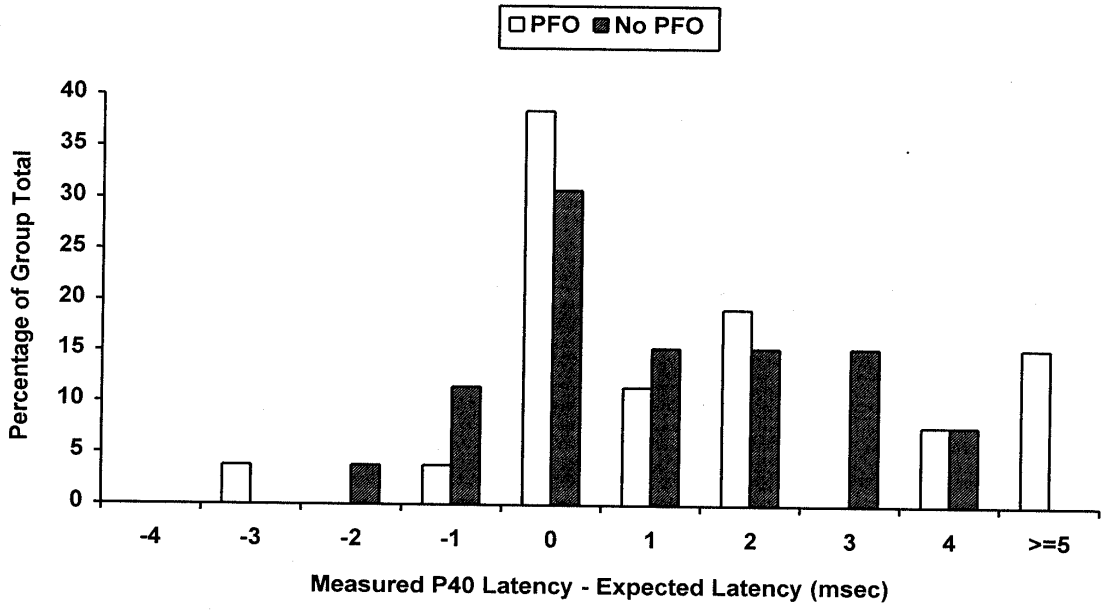

Figure 5 **Measured P40 Latency Relative to Expected Value**

6.3.3.2 DCI Severity Index

Six divers with PFO (Table 93) have suffered a DCS type 2 incident compared to 5 divers with no detected PFO.

Table 93
DCI Severity Index

Group	1-4	5-6	8-10
With PFO (n=8)	2(25%)	3 (37.5%)	3(37.5%)
No P170(n=8)	3(37.5%)	4(50%)	1(12.5%)

6.3.3.3 Diving History

There is no significant difference (two-tailed *t* test;df=26;*p*>0.05) between groups with regard to diving history (Table 94).

Table 94
Diving History

(Mean/Individual)	**With PFO (n=13)**	**No PFO (n=13)**
Years Professional Diving	13.4±3.0 (8-18)	13.5±3.7 (9-21)
Career Dives	995±577 (444-2155)	800±377 (406-1770)
Dives/Year	74±34 (25-149)	60±23 (34-111)
Decompression Days	1081±568 (520-2375)	897±373 (470-1770)
Decompression Days/Year	81±32 (29-149)	68±24 (37-111)

6.3.3.4 Alcohol Consumption

Divers with no detected PFO have a higher weekly level of alcohol consumption but a greater percentage of divers with PFO had a previous higher level of consumption. The level of alcohol consumption per week for each individual is shown in Table 95.

Table 95
Individual Alcohol Consumption per Week

Level (units)	**With PFO (n=13)**	**No PFO (n=13)**
A (1-10)	4(31%)	4(31%)
B (11-20)	4(31%)	2(15%)
C (21-40)	4(31%)	3(23%)
D (41-80)	1(8%)	4(31%)

Years Alcohol Consumption -

With PFO (n=13) = 19.0±2.8(15-24): No PFO (n=13) = 18.6±4.0(8-23)

Average Alcohol Consumption (units/week/individual) -

With PFO (n= 13) = 21.0: No PFO (n= 13) = 30.2

Previous Higher Level of Alcohol Consumption -
With PFO (n=13) = 9 (69%): No PFO (n=13) = 7 (54%)

6.3.3.5 Usage of Drugs of Abuse

Four divers (3 1 %) with PFO have used drugs of abuse compared to 8 (62%) with no PFO. Hard drugs had been used by 4 divers with no detected PFO.

6.3.3.6 Subjective Reports of Long -Term Health *

A greater number of divers with no PFO reported problems with concentration (Table 96).

Table 96
Reports of Long-term Health

	With PFO (n=13)	No PFO (n=13)
Concentration	1(8%)	5(39%)
Memory	6(46%)	7(54%)
Irritability	3(23%)	2(15%)
Depression	3(23%)	2(15%)

6.4 CLINICAL EXAMINATION

6.4.1 Divers with DCI History

Two divers with PFO and 3 with no detected PFO had a significant abnormality (Table 97). The abnormalities were in response to examination of sensation, co-ordination and reflexes. In addition, 4 divers in each group had an abnormality of minor significance. The numbers are too small for valid statistical analysis.

Table 97
Significant Abnormality

Group	on Clinical Examination	Age
With PFO (n=12)	2(17%)	36.7±2.0 (34-41)
No PFO (n=17)	3 (18%)	36.8±5.7 (27-49)
Including abnormalities of minor significance		
With PFO (n=12)	6(50%)	
No PFO (n=17)	7(45%)	

6.4.1.1 Comparison of Abnormalities with regard to Area of Examination

There is little difference between groups in the areas of balance, co-ordination and vestibular examination. With regard to reflexes, the group with PFO have a higher percentage abnormal and in the area of sensation, the group with no PFO have the greater abnormality.

Balance and Co-ordination

Abnormalities (Table 98) were detected in 3 (25%) individuals in the group with PFO (in 1 case, abnormalities were classified as significant) and 4 (24%) in the group with no detected PFO (in 2 cases, abnormalities were classified as significant).

Table 98
Abnormality in

Group	Coordination	Balance	Tremor
With PFO (n=12)	2	1	1
No PFO (n=17)	4	4	-

Sensation

Responses were to light touch/pin prick (LT/PP), two point discrimination (TPD), vibration/proprioception (Vib/Prop) and temperature (Temp). One diver in the group with PFO had a minor abnormality and 3 divers in the group with no detected PFO had abnormalities, of whom 1 had a significant abnormality (Table 99) .

Table 99
Abnormality in

Group	LTIPP	TPD	Vib/Prop	Temp
With PFO (n- 12)	1	-	-	-
No P170 (n= 17)	2	1	1	1

Reflex Responses

Four divers (33%) with PFO had abnormal responses; 1 was classified as significant. Three divers (18%) with no detected PFO had abnormal responses; 2 were classified as significant (Table 100).

Table 100
Abnormality in

Group	Absent Ankle Reflex	Asymmetric Reflex
With PFO (n=12)	2	2
No PFO (n= 17)	1	2

Vestibular

Three divers in each group had abnormalities in this area (Table 10 1). In 2 cases in the group with PFO and in 1 diver in the group with no detected PFO, hearing loss could be attributed to occupational exposure to noise.

Table 101
Abnormality in

Group	Vision	Hearing
With PFO (n=12)	-	3
No PFO (n= 17)	1	3

6.4.1.2 Confounding Factors

Group comparability is as stated in Sections 6.1.1.1. - 6.1.1.6. A higher percentage of divers with PFO (75%) had suffered DCS type 2 compared to divers with no PFO (53%). In addition, 5 divers with no PFO reported a significant head injury. Removal of divers with history of significant head injury has very little effect on results (Table 102).

Table 102
Significant Abnormality

Group	on Clinical Examination	Age
With PFO (n=12)	2(17%)	36.7±2.0 (34-41)
No PFO (n=12)	2(17%)	37.3±6.2 (27-49)
Including abnormalities of minor significance		
With PFO (n= 12)	6(50%)	
No PFO (n= 12)	4(33%)	

There is no difference between groups in the number of individuals with significant abnormality on clinical examination. Minor abnormalities were detected in 4 divers in the group with PFO and in 2 divers in the group with no detected PFO. There is little difference between groups in the areas of balance, co-ordination, sensation and vestibular examination. With regard to reflexes, the group with PFO again have a higher percentage abnormal.

Balance and Co-ordination
Abnormalities (Table 103) were detected in 3 (25%) individuals in each group (in 1 case in each group, abnormalities were classified as significant).

Table 103
Abnormality in

Group	Coordination	Balance	Tremor
With PFO (n=12)	2	1	1
No PFO (n=12)	3	3	-

Sensation
One individual in each group had abnormal responses which were not classified as significant (Table 104).

Table 104
Abnormality in

Group	LT/PP	TPD	Vib/Prop	Temp
With PFO (n= 12)	1	-	-	-
No PFO (n=12)	1	-	-	1

Reflex Responses
Four divers with PFO had abnormal responses; 1 was classified as significant. Two divers with no detected PFO had abnormal responses; 1 was classified as significant (Table 105).

Table 105
Abnormality in

Group	Absent Ankle Reflex	Asymmetric Reflex
With PFO (n=12)	2	2
No PFO (n= 12)	1	1

Vestibular
Three divers in the group with PFO and 2 in the group with no detected PFO had minor abnormalities in this area (Table 106). In 2 cases in the group with PFO, hearing loss could be attributed to occupational exposure to noise.

Table 106
Abnormality in

Group	Vision	Hearing
With PFO (n= 12)		3
No PFO (n=12)		2

Group comparability with regard to diving history, DCI severity, alcohol consumption and usage of drugs of abuse is as stated in Section 6.1.1.6.

6.4.2 Divers with no DCI History

One diver with no detected PFO had a significant abnormality (Table 107). Two divers with PFO and 7 with no PFO had minor abnormalities in the areas of sensation, vestibular and reflexes. The numbers are too small for valid statistical analysis.

Table 107
Significant Abnormality

Group	on Clinical Examination	Age
With PFO (n=5)	-	35.6±4.2 (31-42)
No PFO (n=22)	1(4.5%)	36.3±3.5 (30-43)
Including abnormalities of minor significance		
With P170 (n=5)	2(40%)	
No PFO (n=22)	8(36%)	

6.4.2.1 Comparison of Abnormalities with regard to Area of Examination

No abnormalities were detected in the area of balance and co-ordination. Divers with PFO only had minor abnormalities in the area of vestibular examination in which 1 diver with no detected PFO had a significant abnormalities.

Sensation
Responses were to light touch/pin prick (LT/PP), two point discrimination (TPD), vibration/proprioception (Vib/Prop) and temperature (Temp). No abnormalities were detected in the group with PFO. Minor abnormalities were found in 2 divers with no detected PFO, in response to vibration/proprioception (Table 108).

Table 108
Abnormality in

Group	LT/PP	TPD	Vib/Prop	Temp
With PFO (n=5)	-	-	-	-
No PFO (n=22)	-	-	2	-

Reflex Responses
No abnormalities were detected in divers with PFO. Three divers (25%) with no detected PFO had minor abnormalities (Table 109).

Table 109
Abnormality in

Group	Absent Ankle Reflex	Asymmetric Reflex
With PFO (n=5)	-	-
No PFO (n=22)	-	3

Vestibular
Two divers with PFO had minor abnormalities in this area (Table 110). One diver in the group with no detected PFO had significant abnormalities in this area. Minor abnormalities were found in a further 5 divers in this group. Four had minor abnormalities in hearing in 2 cases this could be attributed to occupational exposure to noise.

Table 110
Abnormality in

Group	Vision	Hearing
With PFO (n=5)	1	1
No PFO (n=22)	2	5

6.4.2.2 Confounding Factors

Group comparability is as stated in Sections 6.1.2.1 - 6.1.2.5. Four divers with no detected PFO reported a significant head injury. In 2 of these divers, no abnormalities were detected on clinical examination. One had a minor vestibular abnormality and the other, minor abnormalities in sensation, vestibular and reflexes. Removal of these divers results in a significant difference between groups with regard to diving history (Section 6.1.2.5) and would have little effect on the findings of the clinical examination with regard to presence of a PFO since divers with PFO only have minor abnormalities in the vestibular area.

6.5 ADDITIONAL REPORTS OF LONG-TERM HEALTH

6.5.1 Divers with DCI History

There is a higher percentage of reported problems from the group with no detected PFO (Table 111), in particular, in response to musculoskeletal pain, hearing, tiredness and reduced alcohol tolerance (RAT). Only divers with PFO reported a problem with anxiety.

Table 111

Health Problem	With PFO (n=12)	No PFO (n=17)
Musculoskeletal Pain	1 (8%)	8 (47%)
Limb Weakness	-	2 (12%)
Headache	3 (25%)	5 (29%)
Hearing	4 (33%)	9 (53%)
Vision	1 (8%)	1 (6%)
Tiredness	-	3(18%)
Confusion	1(8%)	1 (6%)
RAT	4(33%)	8(47%)
Personality/Mood	2(17%)	4(24%)
Anxiety	2(17%)	-

6.5.2 Divers with no DCI History

Total numbers are too small for valid conclusions to be drawn. There is a higher percentage of reported problems from divers with no detected PFO (Table 112) in musculoskeletal pain, confusion and reduced alcohol tolerance (RAT).

Table 112

Health Problem	With PFO (n=5)	No PFO (n=22)
Musculoskeletal Pain	-	4(18%)
Limb Weakness	-	-
Headache	-	2(9%)
Hearing	2(40%)	9(41%)
Vision	-	1(4.5%)
Tiredness	1(20%)	-
Confusion	-	3(14%)
RAT	1(20%)	10(45%)
Personality/Mood	-	1(4.5%)
Anxiety	1(20%)	1(4.5%)

7. DISCUSSION

7.1 HISTORY OF UNTREATED DCI

Previous investigation (Duff *et al*. 1996) had indicated that divers with history of untreated or unreported DCI had a significantly poorer performance on tests of short-term memory, (ie the Logical Memory test and the Rey-Osterreith Test), on the Controlled Word Association test which assess verbal fluency and on the Raven's Matrices (Split-Half) test than divers with history of only treated DCI. In addition, in an unpublished observation, divers with MGL of HMPAO-SPECT brain scan of $\leq$5.5 had a significantly poorer performance on tests sensitive to mild brain injury, ie Symbol Digit test and the PASAT, and on the Raven's Matrices (Split-Half) test when compared to divers with MGL >7.0. It was therefore expected that divers with history of untreated or unreported DCI would have a significantly lower MGL than divers with history of only treated DCI.

This is not the finding here. The reasons for this may be related to the fact that all 31 divers with DCI history could be assessed with regard to neuropsychometry whereas MGL of HMPAO-SPECT brain scan could only be calculated for 22 of these 31 divers. This reduces the number of subjects in the groups to 8 with history of untreated DCI and 14 with history of only treated DCI. As a consequence of this, the difference between groups with regard to DCI severity is increased. On comparison of neuropsychometric performance 50% of divers with history of untreated DCI had suffered a DCS type 2 compared to 63% in the group with history of only treated DCI. On examination of NIGL findings, these values are changed to 37.5% and 79% respectively.

Since it is more likely that divers who have suffered a DCS type 2 may have neurological damage, this could account for the fact that divers with history of only treated DCI have a lower MGL than divers with history of untreated DCI and also have a greater number of subjective reports of problems with concentration, irritability and depression. When divers with a possible significant head injury are removed from the analysis, since this could be a further confounding factor, and the groups are matched for age, the group of divers with history of only treated DCI still have a higher percentage of individuals who have suffered DCS type 2. It is impossible to match the groups under study with regard to DCI history as the total group numbers are too small.

With regard to the comparison of divers with and without history of untreated DCI on abnormality of evoked potential measurement, although neurophysiological assessment was carried out on 28 of the 31 divers with DCI history, total group numbers are too small for valid statistical analysis. However, the results would seem to indicate that history of untreated DCI has no obvious effect on abnormality of brainstem audio evoked potentials (BAEP). There may be an effect on abnormality of Median SSEP and although no statistical difference was noted between total Tibial SEP measurements, there may also be a trend for history of untreated DCI having an effect on abnormality of response.

Removing subjects who have reported either a head injury classified as significant or a possible back injury, reduces the group total numbers substantially. Head injury should have little effect on evoked potential results as the measurement is, in most cases, of a distal sensory deficit. The rationale for removing subjects with a possible back injury is that damage could have occurred due to the injury thus increasing the number of abnormalities detected. This would not seem to be the case in the subjects under investigation here. In the group with history of untreated DCI, none of those who reported a back injury had any detected abnormality on evoked potential measurement. In the group with history of only treated DCI, the number of abnormalities decreased proportionally with respect to the group as a whole.

There would seem to be no obvious difference between groups with and without history of untreated DCI on clinical examination. Only 3 divers from each group were found to have a significant abnormality. There may be slight variation between groups in the area of the abnormality. Divers with history of only treated DCI have a greater percentage abnormality in response to sensation whereas divers with history of untreated DCI have a greater abnormality in reflex response. Again, the numbers are too small for valid statistical analysis. The finding of no obvious difference between groups with regard to the detection of abnormality on clinical examination could be due to a variety of unknown factors. Although the groups are not significantly different with regard to DCI or diving history, the severity of particular episodes of DCI or provocative diving in the past may have caused greater tissue damage in the group of divers with history of only treated DCI under study here. The presence of inert gas bubbles in body tissues and circulation as a result of untreated DCI may not have caused sufficient damage to be detected on clinical examination.

Brubakk *et al*. (1994) reported a correlation between history of untreated DCI and subjective reports of problems with concentration, memory, irritability and depression. In this study, no difference between groups was found with regard to subjective reports of long-term health. One reason for the disparity in findings could be that in this study, almost all divers reported symptoms of skin rash and/or limb pain as being untreated although, in some cases, especially those with 'many' untreated episodes over a considerable time period, exact symptoms were unclear or forgotten. In comparison, in the Brubakk study, 50% of offshore divers with history of untreated DCI had symptoms compatible with affection of the central nervous system. In addition, it had previously been observed that commercial offshore divers in general, both with and without DCI history, have increased subjective reports of problems with long-term health (Shields *et al*. 1996) compared to non-divers. From the Brubakk report, it is unclear as to whether they found that divers with history of only treated DCI suffered any subjective problems with long-term health.

7.2 PRESENCE OF PFO

In examination of the effect of presence of PFO on neurological investigation, valid conclusions are compromised by small group size especially with regard to the group of divers with no DCI history in which only 5 were found to have a PFO. In the group of divers with DCI history, a PFO was detected in 12 individuals but not all of these subjects took part in each neurological investigation.

On examination of effect of presence of PFO on neuropsychometric test performance, for divers with DCI history, subjects with PFO had a significantly poorer performance than those with no detected PFO on the Controlled Word Association test which assesses verbal fluency. However, on removal of confounding factors (ie significant head injury, history of untreated DCI) from the analysis, the result is confusing as divers with no detected PFO had a significantly poorer performance on the Rey-Osterreith Test, a test of short-term memory and divers with PFO again had a poorer performance on the Controlled Word Association Test.

Divers with no DCI history and PFO have a significantly poorer performance on the 1st (slower) trial of the PASAT than divers with no detected PFO but the validity of this finding is questionable due to the small group size and the effect of a more extensive diving history for divers with PFO. In order to overcome any influence of confounding factors, divers both with and without DCI history were matched and the effect of presence of PFO on neuropsychometric test performance examined. The overall conclusion from the analysis of matched pairs of subjects, is that the presence of PFO has no obvious effect.

With regard to any correlation between presence of PFO and MGL of HMPAO-SPECT brain image, results are again compromised by small group size. Divers with DCI history and PFO have a lower MGL than divers with no detected PFO but there is no significant difference between groups. Only 2 divers with no DCI history and PFO could be compared with regard to MGL which is too small a number for valid statistical comparison. Matched pairs of divers were therefore used for

comparison. The MGL for the matched pairs of divers with and without PFO was very similar and not significantly different.

Similarly, the study of an effect of presence of PFO on abnormality of evoked potential measurement, is compromised by total group numbers being too small for valid statistical analysis. However, with regard to divers with DCI history, the results would seem to indicate that presence of PFO has no obvious effect on abnormality of brainstem audio evoked potentials (BAEP) but may have an effect on abnormality of Median SSEP. There would seem to be no effect on Tibial SEP measurement. The initial finding that divers with no PFO have a greater percentage of measured P40 longer than the ULN may be related to the greater number of divers in this group who have suffered a DCS type 2 since on comparison of matched pairs of divers with and without PFO, there is no difference in the percentage of P40 measures longer than the ULN. Removing subjects who have reported a head injury classified as significant has no effect on the number of abnormal responses detected in BAEP and Median stimulation. There is a slight reduction in abnormal Tibial responses but this has no effect on the overall finding. Similarly, analysis in the absence of individuals with significant head injury and/or possible back injury, has no effect on the findings.

Analysis of the effect of presence of PFO on evoked potential measurement in divers with no DCI history, suggests there is no effect on Tibial SEP measurement but there may be an effect on abnormality of BAEP and Median stimulation. However the group total numbers are too small for valid statistical analysis or conclusions to be reached. Comparison of abnormality of evoked potential measurement on matching divers for age, DCI and diving history, suggests that presence of P170 has little effect on abnormality of response. There may be an effect on Median stimulation but again the total group numbers are too small for valid statistical analysis.

On clinical examination, 2 divers with DCI history and PFO were found to have a significant abnormality compared to 3 divers with no detected PFO. The number of abnormalities detected on clinical examination are too small for valid statistical analysis or conclusions to be drawn although there is an indication that divers with DCI history and PFO may have a greater abnormality in reflex response. In the group of divers with no DCI history and PFO, no significant abnormalities were detected but there are only 5 individuals in this group. One diver with neither DCI history nor detected PFO had significant vestibular abnormalities. Valid conclusions could not be drawn with regard to comparisons in different areas of the clinical examination since in the group of divers with neither PFO nor DCI history, only minor abnormalities were noted in vestibular function in 2 individuals.

With regard to additional reports of problems with long-term health, divers with DG history and no detected PFO have a higher percentage of reports of problems with musculoskeletal pain, hearing, tiredness and reduced alcohol tolerance (RAT). Only divers with PFO reported a problem with anxiety. There is no change to this result on removal of divers who reported a head injury classified as significant. These differences may be related to the type and number of DCS type 2 incidents each individual has suffered rather than to the presence of absence of PFO.

Since the number of divers with no DCI history and PFO is small, it is difficult to draw any valid conclusions with regard to reports of long-term health. Again, divers with no PFO reported more problems with musculoskeletal pain and reduced alcohol tolerance.

7.3 COMPARISON TO NON-DIVING CONTROLS

Comparison of divers with and without DCI history to non-diving control subjects on neurological investigation has been reported previously (Shields et al. 1996,1997). A comparison of the results presented here to those of non-divers as stated in these publications can be made, although subject comparability would need to be re-examined before definitive conclusions could be drawn.

With regard to the values for MGL, divers with DCI history as a group (n=22) have NIGI, of 5.99. The MGL values for divers with and without history of untreated DCI and presence or absence of PFO are not dissimilar to this value and are quite different to that of non-diving controls (7.06). The group of divers with no DCI history and PFO are only 2 in number and therefore valid conclusions cannot be drawn.

The percent abnormality in the standard population for neurophysiological examination varies depending on the particular evoked potential measurement under study. In the standard population, percent abnormality for Tibial SEP is 3.4% in individuals and 5% for total measurements; Median SSEP is 5.3% in individuals and 1.3% for total measurements. All the findings of group abnormality in this study are greater than these values whether history of untreated DCI or presence of PFO is being examined. With r regard to BAEP, percent abnormal in the standard population is 2.5%. Only the group of divers with DCI history and PFO, have a percent abnormal for BAEP lower or similar to this value.

In comparison of the neuropsychometric test data for divers with DCI history and presence or absence of PFO with the total group (n=3 1) as published in Shields et al. 1996, the test values vary only slightly apart from the result of the Controlled Word Association Test where divers with PFO have a lower value which could be significantly different to that of the non-diving controls. However, for this comparison to be made, the comparability of the groups with regard to age, years of education and intellectual ability would need to be re-examined. In addition, the group of divers with PFO (n=12) have a higher percentage of subjects who have suffered a DCS type 2 compared to the group as a whole (75% compared to 58%).

It is difficult to draw valid conclusions with regard to the group of divers with no DCI history and PFO since this group consists of only 5 individuals. The results for this group on the PASAT are lower than the group as a whole (n=31) whereas on the SDT, the results are higher. Again, comparability of groups would need to be re-examined.

8. CONCLUSIONS

The total group numbers in this study in most instances are too small for valid statistical analysis, thus the size and comparability of the groups used in this analysis may invalidate the conclusions drawn. However, the following provisional conclusions can be drawn:

1. History of untreated DCI has no effect on MGL of HMPAO-SPECT brain image.

2. History of untreated DCI may have an effect on abnormality of Median SSEP measurement.

3. History of untreated D0 has no effect on the extent of abnormalities detected on clinical examination but may influence the area of damage.

4. Presence of PFO has no significant effect on neuropsychometric test performance or MGL of HMPAO-SPECT brain image.

5. Presence of PFO may have an effect on abnormality of Median SSEP measurement.

6. Presence of PFO has no effect on extent of abnormality detected on clinical examination.

7. To validate these conclusions, analysis is required to be carried out on a larger sample population.

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