Cognitive Symptoms and Welding Fume Exposure

JOHN A. S. ROSS[1*], JENNIFER I. MACDIARMID[2], SEAN SEMPLE[1], STEPHEN J. WATT[1], GILL MOIR[1] and GEORGE HENDERSON[1]

[1]*Scottish Centre for Indoor Air, Environmental and Occupational Medicine, Section of Population Health, University of Aberdeen School of Medicine and Dentistry, Polwarth Building Foresterhill Aberdeen AB25 2ZD UK;* [2]*Rowett Institute of Nutrition & Health, Obesity & Metabolic Health, University of Aberdeen School of Medicine and Dentistry, Polwarth Building, Foresterhill, Aberdeen AB25 2ZD UK*

Background: Prevalence of moderate to severe cognitive symptoms is markedly higher in UK professional divers who have also worked as a welder (28%) than in either divers who have not welded (18%) or offshore workers who have worked neither as a diver nor as a welder (6%).

Objectives: To determine whether cognitive symptoms are related to welding fume exposure or diving.

Methods: Three age-matched groups of male workers were studied using postal questionnaire: professional divers who had worked as a welder (PDW, $n = 361$), professional welders who had not dived (NDW, $n = 352$), and offshore oil field workers who had neither dived nor welded (NDNW, $n = 503$). Health-related quality of life was assessed by the Short Form 12 questionnaire (SF12). Cognitive symptomatology was assessed using the Cognitive Failures Questionnaire (CFQ). A single variable for welding fume exposure (mg m^{-3} days) was calculated, incorporating welding experience in different environments and using different welding techniques and respiratory protective equipment. The level of fume exposure during hyperbaric welding operations was measured during such work as ambient PM$_{10}$ (particles of 10 μm or less). Diving exposure was assessed as the number of dives performed plus the number of days spent working during saturation diving.

Results: Questionnaires were returned by 153 PDW, 108 NDW, and 252 NDNW. SF12 scores were the same in all groups and fell within normative values. Mean (95% CI) CFQ scores were higher in PDW [40.3 (37.7–42.9)] than in both NDW [34.6 (31.6–37.7)] and NDNW [32.1 (30.4–33.9)], but the scores in no groups fell outside the normative range. The mean PM$_{10}$ exposure during hyperbaric welding operations was 2.58 mg m^{-3}. The geometric mean mg m^{-3} days (95% CI) for welding fume exposure in NDW [33 128 (24 625–44 567) $n = 85$] was higher than for that in PDW [10 904 (8103–14 673) $n = 112$]. For PDW the geometric mean (95% CI) diving exposure was 1491 [(1192–1866) $n = 94$] dives and days in saturation. In the general linear model regression analyses adjusted for age, alcohol consumption, and somatization, there was no signification association of CFQ score with either welding fume exposure ($F = 0.072$, $P = 0.79$, $n = 152$) or diving exposure ($F = 0.042$, $P = 0.84$, $n = 74$).

Conclusions: In conclusion, cognitive sympomatology was not related to retrospectively assessed measures of welding fume exposure or diving experience. In addition, the levels of cognitive symptomatology, even in PDW, did not exceed normative values.

Keywords: diving; inhalation exposure; neurobehavioural manifestations; welding

*Author to whom correspondence should be addressed.
Tel: 0112437862; fax: 01224 437285;
e-mail: j.a.ross@abdn.ac.uk.

INTRODUCTION

A cross-sectional questionnaire study of male UK professional divers registered to dive before 1991

indicated that divers more frequently reported moderate to severe 'forgetfulness or loss of concentration' (Ross *et al.*, 2007) than offshore worker controls, and the symptom was associated with reduced performance on tests of verbal memory and visual attention (Taylor *et al.*, 2006). The prevalence of this cognitive symptom was 18% in divers compared with 6% in the control group of offshore workers, whereas it was 28% in divers who had also worked as a welder (Macdiarmid *et al.*, 2004). Welding has been associated with neuropsychological effects due to exposure to manganese (Josephs *et al.*, 2005) and so, from this point of view, there is some concern that divers who weld may be at risk. This concern is amplified by work that demonstrates that divers who weld in hyperbaric welding habitats may be exposed to extremely high levels ($>8 \times 10^6$ particles ml^{-1}) of nanoparticulate fume (mean aerodynamic diameter = 29 nm, SD = 17) (Ross *et al.*, 2009). In animal models, such fume of this particle size has the capacity to directly penetrate into the central nervous system *via* uptake into the olfactory nerves (Elder *et al.*, 2006). Further, toxicological assessment of the fume indicated that it generated inflammation more effectively than crystalline quartz at a dose of 5 μg ml^{-1} (Ross *et al.*, 2009).

The installation and maintenance of undersea oil pipelines requires welding work to be performed on both active and inactive systems under the conditions of increased ambient pressure under water. For manned underwater welding operations, the work piece is enclosed in a metal container, termed a welding habitat, which is then filled with a breathable mixture of helium and oxygen. Atmospheric temperature is controlled to allow human habitation. In a conventional welding shop, fume levels are controlled using general ventilation of the workspace, local ventilation at the weld-piece, and respiratory protection against ozone and other atmospheric pollutants. In a hyperbaric welding habitat, because of the exotic gas environment, general ventilation is used sparingly. Instead, gas from the welding habitat is circulated through a filtration and conditioning system and returned to the habitat atmosphere. This gas conditioning system can control temperature, humidity, carbon dioxide, and dust levels, but it cannot control gaseous contaminants such as argon and carbon monoxide, and undue levels require the system to be ventilated for a while to reduce levels to an acceptable degree. While carbon monoxide and argon levels may be monitored, there is no estimate made of fume exposure in the habitat, and the levels of potential exposure to it are unknown.

The primary aim of this study was to determine whether cognitive symptoms in divers who also had worked as a welder and in welders who had not dived were related to welding fume exposure. A secondary aim was to determine whether such symptoms are related to diving. Accordingly, we have assessed the level of fume exposure during hyperbaric welding operations and conducted a questionnaire study estimating career exposure to welding fume and cognitive symptoms. Since divers working in the offshore oil industry are known to be more likely to express symptoms of any kind than a control population (Ross *et al.*, 2007), allowance was also made for the degree of somatization in the groups studied.

METHODS

A lifestyle, work, and health status questionnaire was posted to participants, in 2004, and nonresponders were sent repeat questionnaires a total of three times, at monthly intervals. No incentives were offered. The study was given a favourable opinion by the Grampian Regional Ethics Committee. Participants were male professional divers who had also worked as a welder (PDW), male professional welders who had not dived (NDW), and male offshore workers who had no experience of either diving or welding (NDNW).

PDW and NDW were identified by their previous participation in a questionnaire study of health and lifestyle in professional divers and offshore workers (Ross *et al.*, 2007). For that study, divers had been identified from the Health and Safety Executive (HSE) records of professional divers' training certificates and were required to have obtained a diving certificate before 1991 and to have a UK address. An age-matched group of offshore workers had been identified from offshore medical records of Capita Health Solutions, Aberdeen, UK (previously Liberty Occupational Health Ltd), who have had an offshore medical examination of fitness to work offshore between 1990 and 1992, held a current UK address, and never dived professionally or recreationally. For the present study, from those responding to the earlier study, all the divers who had reported working as a welder were selected together with an age-matched group of offshore workers. Very few offshore workers identified in this way had worked as a welder, and a new sample was identified from the records of Capita Health Solutions of men who had undergone an offshore medical examination with Capita Health Solutions between 1990 and 2002 and who had stated their occupation as welder but not diver (NDNW).

Participants completed a general demographic, lifestyle, and symptom questionnaire. Experience of 11 symptoms was rated on a four-point scale (0–3) from 'not at all', 'slightly', 'moderately' to 'severely'. The symptoms elicited were as follows: forgetfulness or loss of concentration; joint pain or muscle stiffness; back pain or neck pain; impaired hearing; impaired vision (not corrected by spectacles); breathlessness; cough or wheeze; abdominal pain, diarrhoea, constipation or nausea; skin rash or itch; muscle weakness or tremor; unsteadiness upon walking, dizziness or poor balance. Cognitive symptoms were further assessed by the Cognitive Failures Questionnaire (CFQ). The CFQ assesses self-reported failures of perception and motor behaviour in addition to memory failures. It has been reported to measure failure in the control of attention and memory (Broadbent *et al.*, 1982). As such, it is analogous to 'forgetfulness or loss of concentration', which was the symptom elicited in the initial study on divers and offshore workers (Ross *et al.*, 2007). The CFQ has 25 questions answered on a five-point Likert scale of never (0), very rarely (1), occasionally (2), quite often (3), and very often (4), with a maximum score of 100. Each participant also completed the Short Form 12 health-related quality of life questionnaire from which summary scores for physical quality of life (PCS) and mental quality of life (MCS) were derived (Jenkinson *et al.*, 1996).

Participants completed a welding experience questionnaire. Information was gathered for the number of years and days per year spent using each of five welding techniques. The percentage of time spent in different welding environments and the use of different types of respiratory protective equipment was also reported. Welding fume exposure was estimated using an equation that took into account the welding environment, the use of respiratory protective equipment, different welding techniques, and the time spent on welding (Table 1). Crude base estimates for the welding fume exposure (mg m^{-3}) from each of the different welding types were generated using mean data from van der Wal (1990). These figures were then modified depending on the work environment, degree of ventilation, and the use of respiratory protective equipment. Work by Cherrie (1999) has shown the impact of general ventilation and room size on personal exposure to generated fume. For each welding technique, the likely exposure in each welding environment and for each type of respiratory protection was added to give a variable expressed as the number of days exposed to a time-weighted average concentration of 1 mg m^{-3} welding fume (mg m^{-3} days). The figure calculated for each

Table 1. Weighting factors used in estimating welding fume exposure.

	Geometric mean for level of exposure (SD) (mg m^{-3})	Factor
Welding environment		
Outdoors		0.1
Indoors in a well-ventilated area		1
In a small, poorly ventilated area		10
In a pressurized environment (while diving)		2
Respiratory protective equipment		
Simple dust mask		1
Filter respirator		0.1
Atmosphere supply respirator		0.01
Welding technique fume exposure		
Tungsten inert gas (TIG)	1.2 (1.5)	1
Metal inert gas (MIG)	3.9 (2.5)	4
Flux cored arc (FCA)	3.8 (1.4)	4
Manual metal arc (MMA)	7.1 (2.65)	8
Oxyfuel (OXY)	8.0 (1.4)	8
Flame/arc metal cutting (FAMC)	8.0 (1.4)	8
Other		
Air arc gouging	11.7 (1.4)	12
Plasma cutting	3.3 (1.9)	3
Submerged arc	2.6 (1.55)	3
Automatic welding	—	0

welding technique used was then summed to give a figure for total welding fume exposure.

The degree of welding fume exposure during hyperbaric operations required to be identified for this study. For welding in a pressurized environment, data were gathered during a hyperbaric welding trial. During the trial, welding was carried out in a habitat pressurized to either 500 or 1000 kPa with a mixture of helium and oxygen. The habitat was a cylindrical chamber with domed ends having nominal measurements of 3 m diameter, 8 m length, and 63 m^3 empty volume. PM$_{10}$ (particles of 10 μm or less) was measured in mg m^{-3} using the DustTrak Aerosol Monitor model 8520. A gas sample flow of approximately 15 l min^{-1} was emitted from the container during welding operations using a penetration in the chamber hull plumbed with 1.9-cm-diameter tungum pipe and controlled using a quarter-turn valve outside the chamber. The gas inlet for the sample line was approximately 1 m away from the main weld-piece and was at waist level. The length of pipe descended on the outside of the chamber and allowed gas sampling from it into the analyser. The analyser sample tube was inserted into the open end

of the tungum pipe, and the quarter-turn valve was adjusted to give the necessary free flow. Sampling was therefore performed at atmospheric pressure. Readings were recorded every 5 min and were multiplied by chamber pressure in atmospheres absolute in order to allow for decompression dilution. A total of 20 h of welding was monitored during four welding sessions. The time-weighted average PM_{10} was 2.58 mg m^{-3}.

Divers were asked to detail their use of the five different diving techniques: self-contained underwater breathing apparatus (SCUBA) diving, surface supplied air diving (SSAD), surface oxygen decompression diving (SurDO2), mixed gas bounce diving (MGBD), and saturation diving (SD). These techniques differ in terms of decompression stress and give an indication of the type of industrial environment in which the diver has worked. SCUBA and SSAD are typically associated with inshore and coastal diving. SurDO2, MGBD, and SD are almost exclusive to the oil and gas offshore industry. SD was reported as the number of days spent in a saturation pressure chamber and the other techniques as the number of dives. The total number of dives was then added to the number of days spent in saturation to give an estimate of total diving exposure.

Cross-group comparisons were made using analysis of variance for continuous variables with Scheffe post-hoc comparisons and by Chi^2 tests or unadjusted binary logistic regression for categorical variables. Discrete symptom scores were compared by Kruskal–Wallis tests. CFQ scores were compared between groups using one-way analysis of variance and correlated against the level of 'forgetfulness or loss of concentration'. The tendency of participants to express physical, non-cognitive symptoms was quantified by adding the score for each symptom, excluding that for 'forgetfulness or loss of concentration' to give a non-cognitive symptom score (NCSS) between 0 and 30. The internal reliability of this score (Cronbach's alpha 0.754) was sufficient to allow it to be used for between-group comparisons. Similar scoring systems have been used elsewhere to assess somatization (Kroenke *et al.*, 2002).

Both welding fume exposure and diving exposure data followed a logarithmic distribution. Accordingly, a logarithmic transformation was applied to generate descriptive data and to allow parametric statistical assessment. Exposure data were correlated with CFQ using Pearson's correlation coefficient. A stepped general linear model was developed to allow an adjusted assessment of the relationship between CFQ and welding or diving exposure. Potential confounding factors (alcohol, smoking, education,

industrial accidents, decompression sickness, head injury, NCSS) were assessed by correlation with CFQ. Factors that had a correlation with CFQ of a level of statistical significance of $P > 0.10$ were excluded. The remaining factors were entered into a general linear model together with group membership and age. Factors that had a statistical significance level of $P > 0.05$ were then removed from the model. The relationship between CFQ and exposure was then assessed by entering exposure estimates into the model. A level of $P < 0.05$ was taken as statistically significant. SPSS for Windows (version 17.0, SPSS Inc., Chicago, IL, USA) was used for all data analyses. Assuming a standard deviation for welding fume exposure of 1.7 (van der Wal, 1990) with four predictors in linear regression, 50 subjects would give a power of 0.8 to detect a correlation coefficient of 0.2 or greater, assuming a variance inflation factor of 1.

RESULTS

Three hundred and sixty-one questionnaires were sent to PDW. Of these, 21 were returned as the named individual did not stay at the address, one was excluded due to death, and a further 29 (EDW) were excluded as, although they had originally reported being welders, they did not report this for the current study. Although excluded from the study proper, the prevalence of cognitive symptoms here was calculated to study a potential bias. Three hundred and fifty-two questionnaires were sent to NDW. Of these, 34 were returned uncompleted, and one was excluded due to death. Five hundred and three questionnaires were sent to NDNW with 16 returned uncompleted, and two were excluded due to death. The final number of questionnaires analysed is indicated in Table 2. Of those responding, 65% of PDW, 64% of NDW, and 64% of NDNW responded to the first mailing, and 18% of PDW, 20% of NDW, and 24% of NDNW responded to the second mailing. Late responders did not differ from early responders in any of the criteria elicited. Participant characteristics are shown in Table 2. The groups differed with respect to educational qualifications, since in comparison with NDNW, both other groups were less likely to have a higher education qualification (OR = 0.16, 95% CI: 0.09–0.29 for NWD and OR = 0.42, 95% CI: 0.28–0.65 for PDW). In addition, PDW were more likely to report having had a head injury.

PDW had a higher score for symptoms of 'forgetfulness or loss of concentration' (median 2, IQR 2–3) than both NDNW (median 1, IQR 1–2, $P < 0.001$) and NDW (median 1, IQR 1–2, $P < 0.001$), with no

Table 2. Characteristics of study participants.

	Non-diver, non-welder (*n* = 252)	Non-diver, welder (*n* = 108)	Diver, welder (*n* = 153)	*P*
Age [mean (95% CI) *n*]	50 (46–54) 252	50 (49–51) 108	49 (47–50) 153	0.115
Cigarette pack years [mean (95% CI) *n*]	12.8 (10.5–15.0) 250	12.6 (10.5–15.0) 105	11.9 (9.2–14.7) 147	0.895
Units alcohol week^{-1} [mean (95% CI) *n*]	16.6 (14.9–18.2) 233	14.7 (12.3–17.18) 101	16.6 (14.0–19.1) 143	0.496
BMI (kg m^{-2}) [mean (95% CI) *n*]	27.2 (26.3–29.1) 251	26.9 (26.3–27.6) 103	26.8 (26.4–27.3) 146	0.743
Reported head injury [% (*n*)]	9 (21)	9 (9)	24 (36)	<0.001
Reported 3 day lost time accident [% (*n*)]	26 (66)	31 (33)	53 (80)	<0.001
Decompression illness [% (*n*)]			48 (74)	
Years as a welder [mean (95% CI) *n*]		25 (23–27) 102	17 (15–19) 135	0.023
Years as a diver [mean (95% CI) *n*]			19 (18–20) 145	
Employment status (*n*)	(252)	(108)	(152)	0.142
Employed or self employed (%)	83	89	84	
Unemployed (%)	2	6	2	
Not working—on sickness benefit or retired due to ill health (%)	5	3	7	
Retired (%)	9	3	8	
Higher education (A level, Scottish Higher, HNC/HND, university degree) [% (*n*)]	53 (131)	15 (16)	32 (48)	<0.0001

Table 3. Questionnaire scores (mean and 95% CI).

	Mean scores (95% CI)			*P* values from post-hoc testing		
	NDNW *n* = 212	NDW *n* = 89	PDW *n* = 120	NDNW versus NDW	NDNW versus PDW	NDW versus PDW
NCSS	14.6 (14.1–15.1)	15.7 (14.9–16.4)	16.2 (15.4–16.9)	0.018	0.000	1.000
CFQ	32.1 (30.4–33.9)	34.6 (31.6–37.7)	40.3 (37.7–42.9)	0.225	0.000	0.043
PCS	51.4 (50.2–52.5)	51.0 (49.7–52.2)	49.3 (47.6–51.0)	0.868	0.269	0.699
MCS	51.3 (50.9–52.6)	52.5 (50.9–54.1)	52.6 (50.9–54.2)	0.656	0.599	1.000

difference between the two non-diving groups. The prevalence of moderate or severe 'forgetfulness or loss of concentration' was 14% in NDNW, 11% in NDW, 33% in PDW, and 28% in EDW. Scores for NCSS, CFQ, and health-related quality of life are summarized in Table 3. Welders were more likely to express non-cognitive symptoms whether or not they were divers. CFQ scores were higher in divers than in non-divers, but there was no statistically significant difference between the non-diving groups. CFQ score in EDW (mean = 37.5, 95% CI: 30.5–44.4) did not differ from that in PDW. Health-related quality of life did not differ between groups, and the 95% CI for the scores was within one standard deviation of normative values for all groups. There was a strong correlation between CFQ and NCSS (Spearman's rho = 0.61, *P* < 0.001), and the relationship between the two scores was linear (Fig. 1).

Exposure to welding fume is summarized in Table 4. Eighty-five NDW and 112 PDW, of whom 69 had welded at pressure, completed the fume-exposure questionnaire. The most commonly used technique was MMA with PDW being exposed to approximately one-third of the fume level experienced by
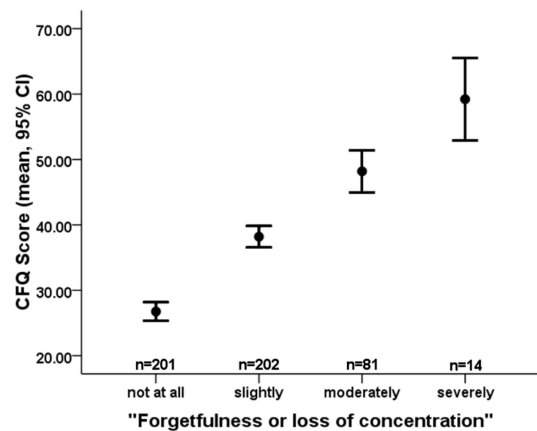

Fig.1. Relationship between CFQ (mean and 95% CI) and 'forgetfulness or loss of concentration'.

Table 4. Welding fume exposure (1 mg m^{-3} days)

Welding technique	Non-diver welder	Diver welder	P
	Log mean (95% CI) n	Log mean (95% CI) n	
MMA	14 263 (10 028–20 281) 83	4545 (3358–6151) 104	<0.001
OXY	1870 (1090–3209) 66	1598 (1076–2371) 90	0.631
MIG	1567 (1030–2385) 77	888 (587–1344) 79	0.057
FAMC	5111 (3309–7894) 77	3770 (2700–5262) 93	0.263
FCA	1071 (651–1762) 53	448 (259–775) 48	0.020
TIG	540 (335–868) 68	160 (98–262) 65	0.001
Other	1694 (460–6238) 11	779 (342–1776) 13	0.263
Total	33 128 (24 625–44 567) 85	10 904 (8103–14 673) 112	<0.001

Total welding fume exposure is for all 197 participants completing the questionnaire. Values for the different diving techniques are for those who used the techniques only.

Table 5. Diving exposure in number of dives or days in saturation.

Diving technique	Log mean (95% CI) n
SCUBA	315 (237–418) 102
SurSupply	377 (282–504) 99
SurDO2	194 (142–266) 88
MixGas	38 (26–55) 58
Days in saturation	345 (241–494) 61
Number of dives plus days in saturation	1491 (1192–1866) 94

Total diving exposure is for all 94 divers completing the questionnaire. Values for the different diving techniques are for those who used the techniques only.

NDW. Diving exposure is summarized in Table 5. Ninety-four divers completed the diving exposure questionnaire. Of these, 88 had used one of the diving techniques typical of work in the offshore oil industry: surface oxygen decompression, mixed gas bounce diving, and saturation diving.

There was no significant correlation between total welding fume exposure and CFQ (Pearson correlation = 0.046, P = 0.54, n = 181). Factors included in the stepped general linear model for CFQ were a history of head injury or industrial accident and a higher education qualification (as random factors) with cigarette pack years, units of alcohol per week, and NCSS as covariates. Group was included as a fixed factor. The final model included age (F = 8.99, P = 0.003), units of alcohol per week (F = 13.81, P < 0.001), NCSS (F = 149.25, P = 0.001), and group (F = 8.56, P < 0.001). The model accounted for 35% of the variance with the estimated marginal mean for CFQ in PDW (38.4, 95% CI: 36.3–40.5) being significantly greater than in both NDNW (32.9, 95% CI: 31.3–34.5) and NDW (34.3, 95% CI: 31.9–34.8). When entered into the model as a covariate, welding fume exposure had no statistically significant effect either overall (F = 0.072, P = 0.79, n = 152) or NDW (F = 0.043, P = 0.84, n = 67) or for PDW (F = 0.251, P = 0.62, n = 85) as individual groups. There was also no significant correlation between CFQ and exposure to welding fume at pressure (Pearson correlation 0.189, P = 0.14, n = 62) and no signification relationship between the two variables in the adjusted model (F = 0.065, P = 0.8, n = 50).

There was no significant correlation between diving exposure and CFQ (Pearson correlation 0.072, P = 0.52 n = 85). When entered into the general linear model as a covariate, diving exposure had no statistically significant effect (F = 0.042, P = 0.84, n = 74).

DISCUSSION

This study confirmed the previous observation that male professional divers who have worked as a welder report more cognitive symptoms than men who have not worked either as a diver or a welder. The primary aim of the study was to identify whether such symptoms were related to welding exposure. Two items of information from the study make such a relationship improbable. First, welders who did not dive had no more cognitive symptoms than control and yet were exposed to significantly more welding fume than diver welders who had a higher prevalence of symptoms. Second, there was no indication of any dose–response relationship between the level of cognitive symptom expression and exposure to welding fume. This result supports the conclusion of a substantive systematic review that exposure-response data did not support the concept of welding being associated with clinical neurotoxicity (Santamaria et al., 2007). It could be argued that exposure to welding fume under hyperbaric conditions is more toxic than at normal pressure, and the toxicity of

some fume constituents is potentiated at pressure (Syversen and Jenssen, 1987). Also, transition metals, such as iron and manganese, have the potential to interact with oxygen metabolism and to amplify the formation of reactive oxygen species in body tissues, triggering oxidative stress and inflammation (Zhu *et al.*, 2007; Bush and Curtain, 2008), and these reactions are potentiated by raised levels of oxygen. The fume encountered while welding at pressure has a high proportion of transition metals (Ross *et al.*, 2009), and saturation divers breathe a raised partial pressure of oxygen, typically 40 kPa, which might amplify fume toxicity. Carbon monoxide exposure also has the potential for causing both acute and chronic neurological effects, and the permitted limits for CO exposure in a hyperbaric welding habitat, at the time the participants were working, were higher than the present industry norm for working at atmospheric pressure (DEA Ltd, 1987). In addition, there is the potential at high pressure for gases that are inert at normal pressure to exert significant pharmacological action with unknown long-term health implications. Argon, for example, can be encountered at levels that cause inert gas narcosis. The degree of all these risk factors, however, would be related to the amount of welding performed at pressure or diving experience, but there was no statistically significant relationship between such exposures and the degree of cognitive symptomatology.

The secondary aim of this study was to determine whether cognitive symptomatology was related to diving. There was no dose relationship between diving exposure and cognitive symptoms as scored by the CFQ, and this is a powerful evidence for the absence of any relationship between diving exposure and symptoms. Nevertheless, cognitive symptoms were more common in divers in a manner not entirely explained by the general tendency in divers to report symptoms of any kind. This supports the observation of a higher level of cognitive symptoms unrelated to somatization in previous work (Ross *et al.*, 2007). It seems, therefore, that it is being a diver rather than the degree of diving exposure that is associated with a higher degree of cognitive symptomatology. It can then be asked whether the degree of symptomatology associated with being a diver is abnormal. The CFQ data from the present study is helpful in considering the point. Four other studies have generated CFQ scores in substantial groups: undergraduates and navy personnel (mean = 43.5, 95% CI: 41.7–45.3, *n* = 335) (Wallace *et al.*, 2002); people over 65 years of age (mean = 32.1, 95% CI: 30.8–33.4, *n* = 270) (Knight *et al.*, 2004); naval recruits (mean = 33.6, 95% CI: 33.1–34.1, *n* = 2379)

(Lanson *et al.*, 1997); and undergraduate students (mean = 45.0, 95% CI: 44.1–45.9, *n* = 475) (Matthews *et al.*, 1990). Although CFQ scores in divers from the present study were higher than the scores in non-divers, none of the groups studied could be considered to have had an abnormally high score in comparison to normative data. Accordingly, the level of cognitive symptomatology in the divers studied is unlikely to be a cause for concern, and this conclusion is supported by the normal scores for physical and mental health-related quality of life observed in this study.

This study has both strengths and weaknesses. The major strength of the study was the method of subject selection. Possible subjects were identified objectively and did not volunteer to receive a questionnaire, therefore minimizing self-selection bias. Basing the inclusion criteria for PDW and NDNW on employment 10 years before the study began minimized healthy worker effects and survivor bias. Healthy worker effects were also reduced by choosing a control group from another equivalent industry but without exposure to diving. Finally, the use of repeated reminder questionnaires established that the sample represented the underlying population, and this is discussed further below.

There were also unavoidable weaknesses related to possible responder bias and the method of exposure assessment. Retrospective assessment of an exposure, as complex as that to welding fume, by a postally administered questionnaire may discourage participants, and it might be argued that impaired individuals would be excluded because of this. Twenty-nine divers in this study, however, who had identified themselves also as welders in a prior study did not complete a welding exposure history but had the same level of cognitive symptoms and CFQ score as divers who did provide an exposure history. We found no evidence, therefore, that failure to complete a welding exposure history was associated with undue impairment. Effective response rate varied from 31% in NDW through 42% in NDNW to 50% in PDW, and it may be thought that the study failed to generate a representative sample of the underlying population. The questionnaires were sent out on three occasions, however, and there were no differences between the three sets of responders. Other work has demonstrated that such an observation indicates that a representative sample has been obtained (Drane, 1991; Unwin *et al.*, 1999). In spite of these considerations, sufficient responding participants were recruited to meet the sample size requirements.

The study found no correlation between exposure and cognitive symptoms. Exposure assessment,

however, related to the average career exposure over a number of years and did not consider short term, possibly accidental, exposures to very high levels of fume. It might be argued that such exposures could themselves cause cognitive issues yet would be unrecorded by the study methodology. Acute neurological toxicity in association with welding fume exposure has not been described, however, and it is more likely that long-term exposure to high levels of fume would cause effects of slow onset (Santamaria *et al.*, 2007).

The exposure assessment method assumes that exposures have not changed with time. Our method used a base exposure as extracted from a study published in 1990 and modified these concentrations with exposure determinants. It is likely that such a method will have underestimated past exposures and overestimated more recent exposures (Creely *et al.*, 2007). Our exposure assessment methodology does not take account of inter-worker variability. Personal exposures to aerosols have been shown to differ by more than an order of magnitude between workers carrying out the same task (Kromhout *et al.*, 1993), and this will have led to some misclassification of exposure that may have reduced our ability to detect an association between welding fume and CFQ.

UK divers working prior to 1991 who also had worked as a welder were more likely to report cognitive symptoms than controls, but health-related quality of life, either physical or mental, did not differ between groups. There was no dose-related association between retrospectively reported welding fume exposure and cognitive sympomatology, the level of which could not be identified as differing from the norm identified in other studies.

FUNDING

REFERENCES

Broadbent DE, Cooper PF, FitzGerald P *et al.* (1982) The cognitive failures questionnaire (CFQ) and its correlates. Br J Clin Psychol; 21: 1–16.

Bush AI, Curtain CC. (2008) Twenty years of metallo-neurobiology: where to now? Eur Biophys J; 37: 241–5.

Cherrie JW. (1999) The effect of room size and general ventilation on the relationship between near and far-field concentrations. Appl Occup Environ Hyg; 14: 539–46.

Creely KS, Cowie H, Van Tongeren M *et al.* (2007) Trends in inhalation exposure--a review of the data in the published scientific literature. Ann Occup Hyg; 51: 665–78.

DEA Ltd. (1987) Suggested limits for contaminants in hyperbaric chambers. Department of Energy offshore technology report OTH 86 262. London: Her Majesty's Stationery Office.

Drane JW. (1991) Imputing nonresponses to mail-back questionnaires. Am J Epidemiol; 134: 908–12.

Elder A, Gelein R, Silva V *et al.* (2006) Translocation of inhaled ultrafine manganese oxide particles to the central nervous system. Environ Health Perspect; 114: 1172–8.

Jenkinson C, Layte L, Wright L *et al.* (1996) The UK SF-36: an analysis and interpretation manual. Oxford: University of Oxford Health Services Research Unit.

Josephs KA, Ahlskog JE, Klos KJ *et al.* (2005) Neurologic manifestations in welders with pallidal MRI T1 hyperintensity. Neurology; 64: 2033–9.

Knight RG, McMahon J, Green TJ *et al.* (2004) Some normative and psychometric data for the geriatric depression scale and the cognitive failures questionnaire from a sample of healthy older persons. NZ J Psychol; 33: 163–70.

Kroenke K, Spitzer RL, Williams JB. (2002) The PHQ-15: validity of a new measure for evaluating the severity of somatic symptoms. Psychosom Med; 64: 258–66.

Kromhout H, Symanski E, Rappaport SM. (1993) A comprehensive evaluation of within- and between-worker components of occupational exposure to chemicals. Ann Occup Hyg; 37: 253–70.

Lanson GE, Alderton DL, Neideffer M *et al.* (1997) Further evidence on the dimensionality and correlates of the cognitive failures questionnaire. Br J Clin Psychol; 88: 29–38.

Macdiarmid JI, Ross JAS, Taylor CL *et al.* (2004) Co-ordinated investigation into the possible long term health effects of diving at work. Examination of the long term health impact of diving: the ELTHI study. Research Report 230. Sudbury: HSE Books.

Matthews G, Coyle K, Craig A. (1990) Multiple factors of cognitive failure and their relationship with stress vulnerability. J Psychopathol Behav Assess; 12: 49–65.

Ross JAS, Macdiarmid JI, Osman LM *et al.* (2007) Health status of professional divers and offshore oil industry workers. Occup Med (Lond); 57: 254–61.

Ross JAS, Semple S, Duffin R *et al.* (2009) Characterisation of fume from hyperbaric welding operations. J Phys: Conf Ser; 151: 012042.

Santamaria AB, Cushing CA, Antonini JM *et al.* (2007) State-of-the-science review: does manganese exposure during welding pose a neurologic risk? J Toxicol Environ Health B Crit Rev; 10: 417–65.

Syversen T, Jenssen J. (1987). High hydrostatic pressure potentiation of the toxic effects of chromate in cell culture. Undersea Biomed Res; 14: 11–9.

Taylor CL, Macdiarmid JI, Ross JAS *et al.* (2006) Objective neuropsychological test performance of professional divers reporting a subjective complaint of forgetfulness or loss of concentration. Scand J Work Environ Health; 32: 311–8.

Unwin C, Blatchley N, Coker W *et al.* (1999) Health of UK servicemen who served in Persian Gulf War. Lancet; 353: 169–78.

van der Wal JF. (1990) Exposure of welders to fumes and gases in Dutch industries: summary of results. Ann Occup Hyg; 34: 45–54.

Wallace JC, Kass SJ, Stanny CJ (2002) The cognitive failures questionnaire revisited: dimensions and correlates. J Gen Psychol; 129: 238–56.

Zhu X, Su B, Wang X *et al.* (2007). Causes of oxidative stress in Alzheimer disease. Cell Mol Life Sci; 64: 2202–10.