References

1. Ries S, Knauth M, Kern R, et al. Arterial gas embolism after decompression: correlation with right-to-left shunting. Neurology 1999;52:401–404.
2. Moon RE, Camporesi EM, Kisslo JA. Patent foramen ovale and decompression sickness in divers. Lancet 1989;1:513–514.
3. US Navy diving manual. Volume 1 (air diving). Flagstaff, AZ: Best Publishing, 1993.
4. Wilmshurst PT, Byrne JC, Webb–Peploe MM. Relation between intraatrial shunts and decompression sickness in divers. Lancet 1989;2:1302–1305.
5. Germonpré P, Dendale P, Unger P, et al. Patent foramen ovale and decompression sickness in sports divers. J Appl Physiol 1998;84:1622–1626.
6. Glen K, Georgiadis D, Grosset DG, et al. Transcranial Doppler ultrasound in commercial air divers: a field study including cases with right-to-left shunting. Undersea Hyperb Med 1995;22:129–135.
7. Jauss M, Kaps M, Keberle M, et al. A comparison of transesophageal echocardiography and transcranial Doppler sonography with contrast medium for detection of patent foramen ovale. Stroke 1994;25:265–1267.

Neurologic outcome of controlled compressed-air diving

Article abstract—The authors compared the neurologic, neuropsychological, and neuroradiologic status of military compressed-air divers without a history of neurologic decompression illness and controls. No gross differences in the neuropsychometric test results or abnormal neurologic findings were found. There was no correlation between test results, diving experience, and number and size of cerebral MRI lesions. Prevalence of cerebral lesions was not increased in divers. These results suggest that there are no long-term CNS sequelae in military divers if diving is performed under controlled conditions.

NEUROLOGY 2000;55:1743–1745

P. Cordes, MD; R. Keil, MD; T. Bartsch, MD; K. Tetzlaff, MD; M. Reuter, MD; A. Hutzelmann, MD; L. Friege; T. Meyer, MD; E. Bettinghausen, MD; and G. Deuschl, MD

In recent years there has been much debate about whether repeated diving over years exerts chronic adverse effects on the CNS. Previous studies have shown neurologic and neuropsychological long-term effects on divers, suggesting spinal and cerebral dysfunction.[1] Most of these studies were performed on divers with a history of neurologic decompression illness (DCI).[2] Furthermore, an increased prevalence of hyperintense cerebral lesions in divers without neurologic DCI has been reported, suggesting a higher risk for accumulating these abnormalities during repeated diving.[3] However, the question of long-term effects on divers without neurologic DCI remains controversial as controlled data regarding neuropsychometric test results, clinical, and MRI findings in this diving population are lacking.

We investigated the neurologic, neuropsychological, and neuroradiologic status of divers without a history of DCI to detect possible deficits and abnormalities that may be attributed to repeated diving. We compared professional military divers with a long-term exposure to compressed-air diving with age-matched nondiving controls.

From the Departments of Neurology (Drs. Cordes, Keil, Bartsch, Meyer, and Deuschl), Diagnostic Radiology (Drs. Reuter and Hutzelmann), and Psychiatry (L. Friege), Christian-Albrechts University of Kiel; and German Naval Medical Institute (Drs. Tetzlaff and Bettinghausen), Kiel-Kronshagen, Germany.

Dr. Cordes is currently affiliated with the Department of Neurology, Braunschweig City Hospital, Germany.

Received May 15, 2000. Accepted in final form August 17, 2000.

Address correspondence and reprint requests to Dr. G. Deuschl, Department of Neurology, Christian-Albrechts University of Kiel, Niemannsweg 147, 24105 Kiel, Germany; e-mail: g.deuschl@neurologie.uni-kiel.de

Methods. *Study groups.* Professional German Navy divers (n = 24) and 24 nondiving Navy employees were matched with respect to age and smoking habits. Subjects had no history of neurologic DCI, head trauma, cerebrovascular or cardiovascular disease, diabetes, or regular drug consumption.

Diving history. Mean diving experience was 1407 ± 675.7 hours ([mean ±SD]; range 500 to 2777 hours) with a mean of 1652 ± 694 dives (range 591 to 3170 dives) and 17.3 ± 5.5 diving years (range 8 to 29 years). The majority (84%) of all dives were performed in the diving depth range of 0 to 20 m.

Neuropsychometric evaluation. The test battery for the assessment of attention included the following subtasks: phasic/tonic alertness, divided attention, go/no-go test, incompatibility, and change of reaction. Memory performance was evaluated with the Wechsler Adult Intelligence Scale–Revised (WAIS-R) (Digit Span), the Corsi Block-Tapping Test, and the Wechsler Memory Scale–Revised (WMS-R) (Verbal Paired Associates). General intellectual functions were tested using the WAIS-R (Information, Similarities, Picture Completion, Block Design). Premorbid level of intellectual abilities was assessed using the German Multiple Choice Vocabulary Test (MWT-B), which is the functional equivalent of the National Adult Reading Test (NART). Verbal fluency (letter/category) of spontaneous speech was evaluated with the Word Fluency Test in the Neurosensory Center Comprehensive Examination for Aphasia (NCCEA). The state of mood was assessed with the Beck Depression Inventory and with a self-rating mood

Table 1 *Subject characteristics*

Characteristics	Divers, n = 24	Controls, n = 24
Age, y	38.7 ± 8.4 (27–52)	9.1 ± 8.7 (26–55)
Height, cm	178.2 ± 6.2 (164–192)	181.8 ± 8.9 (168–203)
Weight, kg	83.2 ± 8.6 (65–105)	87.3 ± 17.1 (59–125)
Smoker/nonsmoker, n	10/14	10/14
Cigarette pack-years	9 ± 11	17 ± 11
Alcohol consumption, n*		
Never	4	2
Rare	17	20
Frequent	3	2
Years of education, %†		
10	92	81
13	8	19

Only one left-handed subject was included, in the control group. Values are mean ± SD (range) unless otherwise noted.

* Alcohol consumption was graded as never, rare ($<$4 times/week), or frequent (5–7 times/week).

† Years of education graded according to the time needed for the achievement of the high school diploma (13 years) or prediploma (10 years).

Table 2 *Comparison of neuropsychometric test results between divers and controls*

Tests	*t*-Test statistics (*p* value)
Attention	
Phasic alertness	0.40
Tonic alertness	0.56
Divided attention	0.037*
Go/no-go test	0.30
Incompatibility	0.24
Change of reaction	0.44
Memory	
Digit Span (WAIS-R)	0.79
Corsi Block-Tapping Test	0.37†
Verbal Paired Associates (WMS-R)	0.37†
Intellectual functions (WAIS-R)	
Information	0.56
Similarities	0.34
Picture completion	0.77†
Block design	0.40
IQ (WAIS-R)	0.81
Premorbid IQ (MWT-B)	0.34
Verbal fluency	
Formal letter fluency	0.08
Category fluency	0.47
Fine motor skills	
Maximal tempo (dom/n-dom)	0.47/0.21
Normal tempo (dom/n-dom)	0.68/0.48
Mood	
Beck Depression Inventory	0.16†
Self-rating mood scale	0.78†

Data from the Incompatibility test, Verbal Fluency tests, and Verbal Paired Associates are presented as sum scores; comparison of single scores of the subtests was also insignificant.

* $p < 0.05$.
† Wilcoxon test statistics.

WAIS-R = Wechsler Adult Intelligence Scale–Revised; WMS = Wechsler Memory Scale; dom = dominant hand; n-dom = nondominant hand.

scale. Fine motor skills were assessed by using the Halstedt–Reitan Test Battery (Finger Tapping Test).

All subjects had a standard neurologic examination.

Neuroradiologic study. Cerebral MRI were performed on a 1.5-T unit. Images were acquired in the transversal (T2-weighted; fluid-attenuated inversion recovery [FLAIR]) and in the sagittal plain (T2-weighted) and were reviewed by two radiologists who were blinded to whether the subject was a diver. Focal hyperintensities were considered as a lesion in a consensus agreement if they were detectable in both T2 and FLAIR images. Signal hyperintensities were classified with respect to topography, absolute number, and size, as well as according to a semiquantitative rating scale.[4]

Statistical analysis. The following tests were applied: Wilcoxon signed rank test or *t*-test for paired samples (group variables), Pearson or Spearman correlation coefficient (correlation analysis), and the χ^2 test (MRI study).

Results. The groups did not differ with respect to subject characteristics (table 1). Neurologic examination findings were unremarkable. *Neuropsychometric results.* In the divided attention subtest significantly longer reaction times were obtained from the divers (table 2). Divers showed a lower rate of recall in the first trial ($p = 0.041$) and delayed recall in the fourth trial ($p = 0.035$) as well as a higher rate of forgotten pairs in the fourth trial ($p = 0.011$) of the subtest Verbal Paired Associates (WMS-R). However, the total sum scores for the immediate and delayed recall were not different between groups. No significant differences were found in the other neuropsychometric tests (see table 2). Furthermore, no significant correlations among neuropsychometric test results, diving indices, or alcohol or nicotine consumption were obtained.

MRI study. Six divers (25%) showed a total of 10 hyperintense lesions, whereas 24 lesions were revealed in 10 controls (42%). Most signal hyperintensities were found in the subcortical parietal white matter (divers 5 lesions; controls 13 lesions). Otherwise, the distribution was as follows: subcortical frontal white matter (divers 2 lesions; controls 6 lesions); putamen (controls 3 lesions); thalamus (divers 2 lesions); internal capsule (controls 1 lesion); pons (divers and controls 1 lesion each). There was no difference in the absolute number and size of cerebral lesions between the groups or in a rating scale.[4] Also, there was no correlation to the diving indices, neuropsychometric test results, or alcohol and nicotine consumption. A megacisterna magna was described in one diver and a mild frontal lobe atrophy in another.

Discussion. A longer reaction time in a visual reaction time test has been shown in compressed-air divers without a history of neurologic DCI.[5] However, an examination of divided attention by the Trail Making Test (TMT-B) did not reveal any differences between groups.[5] Compared to our group these divers had almost twice as many dives, although their total diving years and the mean age were comparable. In elderly compressed-air divers with a much longer diving experience an impairment in visual tracking and scanning and recall of nonverbal material compared to controls has been reported.[6] Similar to our study, divided attention was significantly decreased in these elderly divers as analyzed by the TMT-B. Because impairment of divided attention may be the earliest indicator of cortical dysfunction[7] these findings in middle-aged and elderly divers may point to a certain effect of repeated diving. However, when comparing our results with other diving populations, this putative impairment in divers seems not to increase with longer diving experience.[5,6] Considering this, and that all results in our detailed neuropsychometric testing are subclinical and within the range of the applied tests, we did not find evidence for a clear impairment of neuropsychological performance due to long-term diving in our military population exposed to carefully controlled diving. Thus, our psychometric results are in line with studies in which no overt neuropsychological impairment was found that would suggest that an accumulation of subclinical decompression incidents results in distinct neuropsychological deficits.[8]

The long-term effect of compressed-air diving without neurologic DCI on the number of cerebral focal hyperintensities is controversial as a higher number of lesions in self-recruited amateur divers has been reported.[3] This discrepancy may partly be explained by the recruitment protocol of the study,[3] which has been criticized elsewhere.[9] A correlation between the number and size of MRI abnormalities and the time spent in the deep air-diving range of 40 to 60 m was found in elderly divers.[6] However, the total number of lesions did not differ significantly from the controls.[6] This population[6] consisted of older divers with a mean age of 50 years, which may partly account for a higher number of abnormalities, which increase with age.[10] Our MRI findings are in line with other MRI studies in which no increased prevalence in cerebral hyperintense lesions was found and the range of signal hyperintensities corresponded to those reported for asymptomatic individuals.[6,10] We conclude that neither neuropsychological nor MRI abnormalities can be detected in professional divers without decompression illness if diving is performed under controlled conditions.

Acknowledgment

The authors thank Dr. S. Sievers for recruiting the study participants.

References

1. Calder I. Does diving damage your brain? Occup Med (Lond) 1992;42:213–214.
2. Peters BH, Levin HS, Kelly PJ. Neurologic and psychologic manifestations of decompression illness in divers. Neurology 1977;27:125–127.
3. Reul J, Weis J, Jung A, Willmes K, Thron A. Central nervous system lesions and cervical disc herniations in amateur divers. Lancet 1995;345:1403–1405.
4. Scheltens P, Barkhof F, Leys D, et al. A semiquantative rating scale for the assessment of signal hyperintensities on magnetic resonance imaging. Neurol Sci 1993;114:7–12.
5. Bast-Pettersen R. Long-term neuropsychological effects in non-saturation construction divers. Aviat Space Environ Med 1999;70:51–57.
6. Tetzlaff K, Friege L, Hutzelmann A, Reuter M, Holl D, Leplow B. Magnetic resonance signal abnormalities and neuropsychological deficits in elderly compressed-air divers. Eur Neurol 1999;42:194–199.
7. Parasuraman R, Haxby JV. Attention and brain function in Alzheimer's disease. Neuropsychology 1993;7:242–272.
8. Edmonds C. The mythology of divers dementia. In: Hope A, Lund T, Elliott DH, Halsley MJ, Wiig G, eds. Long term health effects of diving. Flagstaff: Best Publishing, 1994:229–242.
9. Hovens MM, ter Riet G, Visser GH. Long-term adverse effects of scuba diving. Lancet 1995;346:384. Letter.
10. Rinck PA, Svihus R, de Francisco P. MR imaging of the central nervous system in divers. J Magn Reson Imaging 1991;1:293–299.