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Evaluation of cognitive performance in professional divers by means of event-related potentials and neuropsychology

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HIGHLIGHTS

- We investigated the effects of occupational diving on brain functions by ERPs and neuropsychology.
- Some ERP parameters were influenced by diving exposure, and P3 effects were graded by the exposure.
- Extensive diving subgroup displayed poor visuo-construction and visual episodic memory.

ABSTRACT

Objective: We investigated whether professional air diving with no decompression illness causes any long-term changes in cognitive functions.
Methods: The all-male participants consisted of 18 healthy control (HC) volunteers and 32 divers. Divers were divided into two subgroups as moderate exposure group, Divers-I (DI) and extensive exposure group, Divers-II (DII). Participants were administered a comprehensive neuropsychological battery and event-related potentials (ERPs) were recorded while they performed auditory oddball task and visual continuous performance test (CPT).
Results: P3 waves in oddball and CPT were significantly attenuated and peak latencies were prolonged in both diver groups compared with HC. Amplitude decrements in CPT P3 were graded with respect to level of diving exposure. Neuropsychologically, DII group displayed significantly poorer performance than HC and DI groups in measures of visuo-constructional and visual long-term memory tests. DI group performed better than HC group in some measures of planning ability.
Conclusions: Most of the changes in neurophysiological measures and poorer neuropsychological performance were found in DII group, and this might be interpreted as a red flag for the reflection of the slowly progressing deleterious effects of silent bubbles in brain function.
Significance: This study reports impairments in certain neuropsychological measures and apparent neurophysiological markers pointing to slow cognitive decline referring to long-term effects of diving.

1. Introduction

Decompression illness (DCI) is a term used for pathophysiological conditions associated with decompression (Vann et al., 2011; Moon, 1997). While diving, the ambient pressure may drop below the body inert gas tensions during decompression phase (supersaturation), and at a critical point (critical supersaturation) inert gas separates in the bodily fluids and tissues producing gas bubbles. These bubbles may cause local effects or circulate as venous gas emboli. In case of passing through pulmonary or cardiac shunts to the arterial circulation they become arterial emboli (Vann, 2004; Moon, 1999; Blatteau et al., 2006).These inert gas microbubbles, when occurring without any acute clinical signs, historically have been termed 'silent bubbles'(Behnke, 1951), and have been generally assumed to have no negative effects. Although silent bubbles are by themselves asymptomatic, the occurrence of many

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bubbles is clearly linked to a high risk of DCI (Nishi, 1990; Cimsit, 2009).

DCI can affect many systems, its effects on the nervous system are considered to be the most serious (Newton, 2001; Knauth, 2008; Hawes and Massey, 2008; Grønning and Aarli, 2011). Although the relationship between DCI and neurologic damage is obvious, the long-term neurologic effects of diving in divers without history of DCI are far from being unquestionably established. In a recent review by Grønning and Aarli (2011) on the neurological effects of deep-sea diving, the authors concluded that although the immediate and transient neurological effects after deep dives are documented, the results from the epidemiological and clinical studies regarding long-term neurological effects from deep diving are conflicting and still inconclusive.

One observational study reported more general nervous system complaints, most prominent of which were difficulties in concentration and problems with long and short-term memory in professional divers without DCI than controls (Todnem et al., 1990). Cerebral microvascular dysfunction due to gas microembolism is considered as a possible mechanism of long-term neurologic effects (Moen et al., 2010). A number of MRI studies on divers showed increased number of hyperintense white-matter lesions (Tetzlaff et al., 1999; Erdem et al., 2009; Gempp and Blatteau, 2010) and widespread cerebral white matter diffusion changes (Moen et al., 2010) supporting the microvascular dysfunction hypothesis, while others did not (Cordes et al., 2000; Hutzelmann et al., 2000; Koch et al., 2004).

One autopsy study of divers who had died after diving accidents found perivascular lacuna formation in cerebral and/or cerebellar white matter, necrotic foci in grey matter and unilateral necrosis of the head of the caudate nucleus, implicating the bubble as the damaging agent of the cerebral small vessel wall (Palmer et al., 1992). The positive findings suggest that gas microembolism in divers may result in a state similar to that is caused by subcortical ischemic vascular disease (SIVD).

The relationship between SIVD and dysexecutive syndrome is well-established. The executive functions, mediated by prefrontal cortex, include those high level abilities such as abstraction, planning, response inhibition, set-shifting and impairment of these abilities is called dysexecutive syndrome. It has been shown that SIVD, resulting in cognitive impairment, presents with a profile of dysexecutive syndrome (Kramer et al., 2002). The executive dysfunction is also found in asymptomatic individuals with white matter lesions and/or lacunar infarctions (Reed et al., 2004). Another study indicated that regardless of where in the brain these white matter hyperintensities (WMH's) are located, they are associated with frontal hypometabolism and executive dysfunction (Tullberg et al., 2004), supporting the notion that WMHs cause multiple disconnections disrupting the top-down control of the prefrontal network.

The neuropsychological studies on divers with no history of DCI are few in number and their results are somewhat conflicting. Some of these studies point out slight decline in domains such as mental flexibility, inhibition in attentional tasks (Tetzlaff et al., 1999; Slosman et al., 2004), while others report no evidence for such a decline other than longer reaction times (RTs) (Bast-Pettersen, 1999; Cordes et al., 2000). In a study, a mild memory decline was shown by neuropsychological tests on divers with subjective complaint of forgetfulness and this was related with number of dives with gas bounce diving and surface oxygen decompression techniques (Taylor et al., 2006).

Although electroencephalogram (EEG) and event-related potentials (ERPs) provide noninvasive measures for studying brain activity, those methods are rarely used to investigate the long-term neurologic effects of diving. Todnem et al. (1991a) reported focal slow waves in the temporal regions and sharp potentials in 18% of the divers, and these abnormal waveforms were correlated with the exposure to saturation diving and prevalence of decompression sickness. The same group also reported that brainstem auditory evoked potential (BAEP) latencies were increased in the diver groups (Todnem et al., 1991a). However, they reported no abnormal finding in latencies of visual evoked potentials (N75, P100, N145) and brainstem auditory evoked potential, in commercial saturation divers (Todnem et al., 1991b).

In addition to early sensory evoked brain potentials, ERPs with other long-latency brain potentials such as P3 are broadly used to investigate cognitive processes. These brain potentials are well known to be sensitive to several types of cognitive impairments (Polich, 2004), and oddball paradigm has been the most widely recruited cognitive task in these studies. Continuous performance test (CPT) is another widely used cognitive task, and the AX-type CPT involves attention and inhibition systems, which provide basis for executive functions. ERPs during CPT performance are reported to be affected (amplitude decrements and prolonged latency) in certain neuropsychiatric patient groups (Riccio et al., 2002; Fallgatter et al., 2004).

Although our main concern in designing this study was to clarify if prolonged exposure to the extreme conditions as posed by the professional SCUBA (self-contained underwater breathing apparatus) diving had any deleterious effect on cognitive functioning, on the other hand, we were also aware that this profession, which necessitates the development and acquisition of highly specific skills might have resulted with some cognitive gains that could be reflected positively in some neuropsychological test scores and/or in some ERP recording measures.

The aim of this study was to combine a comprehensive neuropsychological test battery (NTB) and ERP recordings in order to investigate the occurrence of likely losses and gains in cognitive functioning in professional air SCUBA divers without history of neurological DCI.

2. Methods

2.1. Participants

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethical Committee of the Istanbul Faculty of Medicine. All participants gave written informed consent after the aim of the study and the data collection procedures were fully explained to them.

A total of 50 right-handed male volunteers (age range 25–45 years) consented to participate in the study. All participants were in good physical health and none of the participants were taking any medication. Diver groups consisted of professional air SCUBA divers who were employed as diving instructors. Their diving histories, including years of diving experience, total number of dives, average depth (msw), average bottom time (min), deepest dive (msw) and deepest dive time (min) was obtained by a questionnaire. The U.S. Navy Standard Air Decompression Tables were used during the dives. All diver participants had an average depth less than 40 msw and none of them had a history of DCI.

Participants were divided into 3 groups as follows: Healthy Control (HC) = participants with no diving experience ($n = 18$), and divers according to their diving experience: Divers-I Group (DI) = Professional divers with moderate diving experience (1000–2000 dives) ($n = 16$), Divers-II Group (DII) = Professional divers with extensive diving experience (2001–4000 dives) ($n = 16$).

The divers participated to this study following their annual physical examination of head-neck, ear-nose-throat, nervous, respiratory, cardiovascular, gastrointestinal, and genitourinary sys-