Original articles

Evaluation of critical flicker fusion frequency and perceived fatigue in divers after air and enriched air nitrox diving

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Key words
Scuba diving, air, enriched air – nitrox, nitrogen narcosis, inert gas narcosis, performance, visual analog scale

Abstract
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Introduction: Many divers report less fatigue following dives breathing enriched air nitrox (EANx) compared with breathing air. A reduction of post-dive fatigue with EANx would suggest a pathological origin, possibly the presence of asymptomatic nitrogen bubbles in the body after a dive.

Method: We studied fatigue in 219 healthy divers performing either an air (n = 121) or EANx32 (oxygen 32%, nitrogen 68%; n = 98) dive to 21.2 ± 4 metres' sea water for 43.3 ± 8.6 minutes in tropical open-water conditions. Divers were assessed pre-dive and 30–60 minutes after surfacing using a visual analog scale (VAS) of fatigue and critical flicker fusion frequency (CFFF).

Results: The two groups were comparable in sex ratio, age and diving experience. The change in perceived fatigue level after a single dive was significantly lower when EANx was breathed compared to air dives (VAS; $P < 0.001$). Compared to pre-dive, CFFF decreased by 6% in the air group ($P < 0.01$) but increased by 4% in the EANx group ($P < 0.05$). The post-dive difference between the two groups was highly significant ($P < 0.001$).

Conclusions: Three hypotheses should be considered to explain the difference in post-dive fatigue and alertness between the air and EANx groups: a nitrogen effect, an oxygen effect and a bubble effect. These involve complex phenomena in the functional modifications of the nervous system in hyperbaric environments according to the type of gas used for the dive, and more research will be required to elucidate them.

Introduction

Within recreational scuba diving, air is the most commonly used breathing gas, but since its introduction to the diving community in 1985, the use of enriched air nitrox (EANx: any gas combination of oxygen and nitrogen where the oxygen fraction is greater than 21%) has become widespread. In some diving centres it is now almost impossible to obtain an 'air-only' fill.

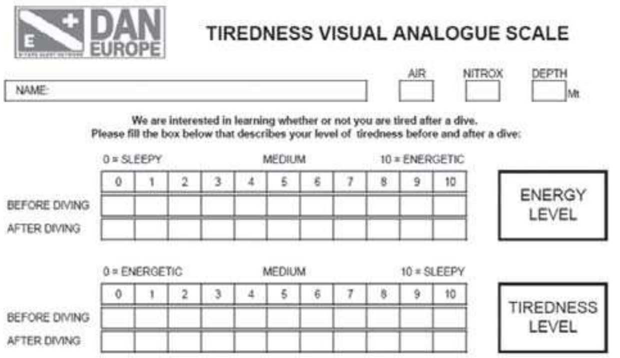
Because of the reduced nitrogen fraction, the main advantage of EANx diving lies in longer bottom times without additional decompression requirements, compared to an air dive at the same depth. The diving community also attributes several other, unproven benefits to EANx use, such as lower gas consumption (due to the higher percentage of oxygen in the mix) and reduced severity of any barotrauma (improved circulation due to high blood oxygenation and lower nitrogen level, implying fewer nitrogen bubbles). The reduced level of nitrogen has also been claimed to reduce feelings of tiredness or fatigue following a dive.[1]

Although multifactorial, fatigue may be an important symptom as it can be a manifestation of decompression stress or decompression sickness (DCS).[2,3] A reduction of post-dive fatigue by the use of EANx would suggest a pathological origin for this fatigue, ascribed to the presence of asymptomatic nitrogen bubbles in the body after a dive.[4] For the time being, there are only anecdotal reports of reduced fatigue with EANx, while one controlled study with simulated (dry chamber) dives showed no measurable difference in fatigue, attention levels or ability to concentrate.[5,6] An objective, in-the-field measurement tool is thus needed to verify this assertion and evaluate the neuropsychometric effects, if any, of diving with air or EANx. We report a field study using a visual analog scale (VAS) of fatigue and a critical flicker fusion frequency (CFFF) test in a large group of divers.

Methods

After ethical approval and written informed consent, 301 healthy divers (97 female, 204 male) volunteered for this study, which was carried out at Sharm-El-Sheikh, Egypt, over a two-month period. All volunteers were certified divers and assessed fit to dive prior to entry into the study. Because of the measurement method used (see below), divers with visual impairment were excluded unless they used their

Figure 1
Visual analog scale presented twice in opposite directions: one evaluates the 'energy level' (from sleepy/0 to energetic/10), the other evaluates the 'tiredness level' (from energetic/0 to sleepy/10)



correction lenses during the test. Divers using medications such as steroids, benzodiazepines, barbiturates, or any other psychoactive drugs were also excluded.

Participants were asked not to drink any alcohol- or caffeine-containing beverages before and after the dive. Each subject performed a single dive at least 12 hours after any previous dives, breathing either air or EANx32 (32% oxygen, 68% nitrogen). No diving restrictions were imposed except for a maximum depth of 30 metres' sea water (msw), required by local Egyptian law. All divers performed a multi-level dive, in the nitrox group ranging from 14 to 29 msw, with a total immersion time between 32 and 69 minutes, and in the air group between 12 and 28 msw, with a total immersion time between 31 and 71 minutes.

Decompression was made according to each diver's personal dive computer. When diving with EANx, the dive computer was set for an EANx32 mix. Although many different dive computers were used, dive profiles were similar and decompression was most often limited to a single safety stop of 5 minutes at 5 msw.

Fatigue was assessed before and 30–60 minutes after the dive using a 100 mm visual analog scale (VAS). In order to test the attention and comprehension of the diver, the same scale was presented twice but in opposite directions: one asked to evaluate the 'energy level' (from sleepy/0 to energetic/10), the second asked to evaluate the 'tiredness level' (from energetic/0 to sleepy/10) (Figure1). After the first evaluation, 71 divers were excluded because of lack of coherence in the results, possibly due to difficulties in comprehension, language problems or complacency in doing the test.

Alertness was tested using critical flicker fusion frequency (CFFF), defined as "*the frequency to which a stimulus of intermittent light seems to be completely stable to the observer*".[7,8] The device used was designed and built by Human Breathing Technology (HBT Technology, Trieste, Italy), specifically for this project and future underwater use. In brief, the waterproof device consists of a rotating ring, surrounding a short cylindrical housing of 8 cm diameter containing the numeric (digital) frequency indicator. Attached to this waterproof housing is a flexible cable, to whose end is attached a single blue LED (Light Emitting Diode – 8000 K) enclosed in a smaller cylindrical container (so as to shield it from stray light and reflections). While the subject to be tested is looking straight at the LED at a distance of 50 cm, the investigator turns the dial slowly clockwise in order to increase (fuse) the flicker frequency. When the test subject indicates that no more flickering is perceived, the value is noted by the investigator. As there are no markings on the dial, nor a visible 'starting position', the test subject has no indication whatsoever of the actual flicker frequency of the LED. This test was repeated three times from flickering to fusion, and the mean value was noted as the CFFF. When the three results differed more than 5% from one another, the result was rejected as aberrant. Another 11 divers were excluded for aberrant results leaving a total of 219 divers for analysis.

Standard statistical analysis was performed, including means and standard deviations, and ANOVA for repeated measures to test the between- and within-subjects effect after Kolmogorov-Smirnov test for normality of distribution. The researchers who analysed the data were blinded to the condition of the diver (air or EANx). GraphPad Prism version 5.00 for Windows (GraphPad Software, San Diego, California, USA) was used on a personal computer. Taking the initial value as 100%, procentual variations were calculated for each parameter (VAS, CFFF), allowing an appreciation of the magnitude of change rather than the absolute values. A probability of <0.05 was considered statistically significant.

Results

Divers' demographic and dive data are presented in Table 1. With regard to the dive performed, the EANx group had, on average, slightly deeper and longer dives than the air group ($P > 0.05$, one way ANOVA).

Table 1
Divers' demographics with diving experience and dive parameters (all subjects), SD in parenthesis

Demographics	**Air** (n = 121)	**EANx** (n = 98)
Sex ratio (♂/♀)	77/44	68/30
Age (years)	44.9 (11.8)	44.7 (11.1)
Diving experience		
Total years	8.2 (6.2)	6.2 (5.5)
Total logged dives	352 (347)	322 (524)
Depth (msw)	20.4 (4.3)	21.9 (3.8)
Dive duration (min)	42.5 (7.9)	44.2 (9.3)

Figure 2
Procentual variation of the visual analog scale of perceived fatigue ($P < 0.01$**, ns - not significant)**

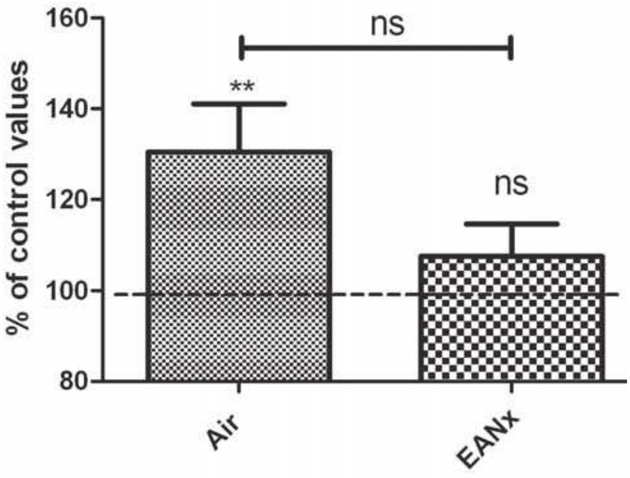


Figure 3
Procentual variation of critical flicker fusion frequency (*** $P < 0.001$**; **** $P < 0.01$**; *** $P < 0.05$**)**

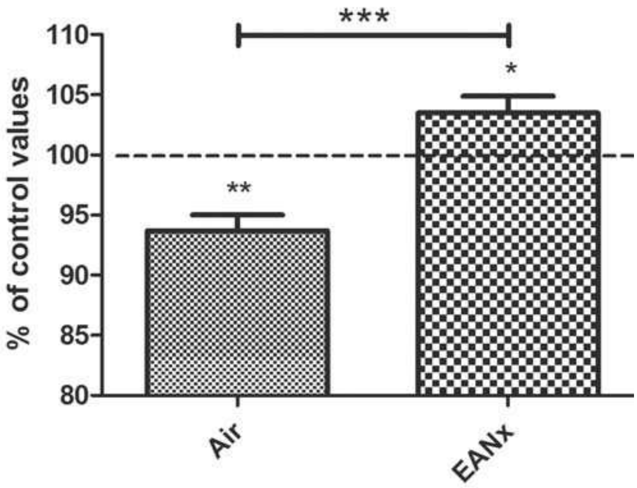


Figure 2 shows the results of the VAS evaluation. It can be seen that the perceived fatigue is significantly higher after the air dives compared to pre-dive ($P < 0.001$, two-tailed paired t test, t = 1.872). On the other hand, the difference between pre- and post-dive breathing EANx was not significant. Figure 3 shows the results of the CFFF, in which the difference was significant. It was decreased 6% in the air group but increased 4% in the EANx group post-dive. ($P < 0.01$ and $P < 0.05$ respectively). The difference between the two groups was highly significant ($P < 0.001$, one-way ANOVA).

Discussion

As the visual analog scale is a widely used and validated measure of subjective sensation, such as pain and fatigue, it should be the ideal tool for quantifying and comparing divers' self-reported fatigue.[9,10] This method has been used in two previous studies that have, however, produced conflicting results.

In the first study, a simulated dry dive in a hyperbaric chamber was performed, controlled for depth, bottom time, decompression rate, temperature and physical exertion.[6] Subjects were blinded as to their breathing gas (EANx or air) and after the dive reported no subjective difference in fatigue. However, even with the air dive, fatigue did not increase at all, casting doubt on the extent to which the simulated dive reflected 'real-life' diving. As fatigue is commonly reported following recreational underwater diving, the authors agreed the simulated dives probably differed in many respects to actual underwater diving; thus they and others expressed a need for reliable in-the-field measurement.[6,11,12]

In the only previous field measurements reported, a major bias is likely, since the EANx divers had shorter total immersion and decompression times than the air dives with which they were compared.[5] As energy expenditure increases due to physical exertion and thermoregulation, we may hypothesize that (perceived) fatigue could be higher after a longer dive than after a shorter one.

For our study, divers from both groups performed their dives at the same dive sites at the same time and, thus, had similar diving conditions in terms of visibility, current and water temperature. Weather variations related to the study time span (two months) may have occurred, but were not documented. Although there is no statistically significant difference between the two groups, the absolute values of the diving parameters are unfavourable for the EANx group, who had slightly deeper and longer dives (EANx group 21.93 ± 3.8 msw, 44.17 ± 9.33minutes; air group 20.4 ± 4.3 msw, 42.48 ± 7.89 minutes). Therefore, the increased post-dive fatigue seen in the EANx group cannot be attributed to the conditions in which the experiment was performed.

To increase the reliability of the VAS evaluation, each diver was tested twice with reversed scales. Only if the scores on both scales were coherent, was the result considered valid. In 71 divers the scores were not coherent. According to the VAS, the EANx dives do not seem to provoke any post-dive increase in perceived fatigue. On the other hand, after air dives, perceived post-dive fatigue increased significantly. This result seems to support the subjective claims of EANx divers, but would need to be confirmed by a more objective and reproducible measurement than the VAS.

Although CFFF depends on several factors, such as the spectral composition of the light source, its average brightness, size, and retinal position, it is also a brief, easy and economical measure of vigilance.[9,13] Indeed, some authors have emphasised the advantages of CFFF assessment as an objective, quantitative and important method for measuring alertness and arousal.[14–16] CFFF measurements have been shown to be highly reproducible.[17] When executed in standard conditions, the CFFF test thus makes it possible to determine in a longitudinal way the evolution of the degree of fatigue and cortical arousal in test subjects.

CFFF has been used in deep saturation diving.[18] In that study, CFFF variations were grossly parallel to EEG modifications and probably revealed neuropsychological impairment (including fatigue) that was not apparent from subjective reports. In our study, the diver was blinded to the actual results. Analysis of the changes in CFFF response shows a marked difference between the air and EANx groups, with improvement of alertness with EANx and impairment with air breathing. These differences in response were highly significant statistically.

In order to explain the difference in post-dive fatigue and alertness between the air and EANx groups, three hypotheses should be considered: a nitrogen effect, an oxygen effect and a bubble effect.

Nitrogen: Nitrogen gas is known to have a degree of anaesthetic potency, related to its lipid solubility (Meyer-Overton rule), possibly due to interaction at the lipid bi-layer of neuronal membranes, altering their function.[19] While this theory is an oversimplification, it could explain why more nitrogen could lead to more fatigue. Recent studies have shown impaired psychomotor processing during air exposures from 204 to 408 kPa suggesting that nitrogen narcosis occurs even at relatively shallow depths.[15,16] No comparisons with EANx diving have been made.

Oxygen: During the EANx dive, the inspired PO_2 was 103 ± 45 kPa. Normobaric hyperoxia has been shown to facilitate nerve conduction, probably due to oxidative stress.[20] Several potential mechanisms, which will not be discussed here, have been proposed to explain this. The consequence of these is inhibition of inhibitory cerebral pathways, which could account for the enhanced cerebral arousal measured by the CFFF. Although tempting, this assumption must take into account that air divers also had an elevated PO_2 (64 ± 29 kPa), so the time spent at depth is probably too short to explain the difference observed.

Bubbles: Decompression schedules that have a high K-value (K = rate of decompression/partial pressure of inspired oxygen) generate more decompression stress.[21] Given the fact that, in our study, decompression rates were the same, the use of EANx would likely have produced a less 'stressful' decompression. Since a recent thermodynamic analysis suggests that bubbles are the bi-stable hydrophobic gates responsible for the on-off transitions of single-channel currents, we may also hypothesize a bubble effect.[22]

The complexity of these phenomena, which we have only touched upon briefly here, make it, as yet, impossible to draw any conclusions as to the various factors contributing to fatigue after a dive.

Conclusions

We have shown that, in a large group of divers, perceived fatigue after a single dive, as evaluated by a VAS, was significantly less when EANx was breathed, compared to air. Objective measurements of critical flicker fusion frequency also showed impairment with air breathing but slight improvement with EANx. More studies are needed in order to fully explore the complexity of the phenomena involved in the functional modifications of the nervous system in hyperbaric environments according to the type of gas used for the dive.

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