Measurement of fatigue following 18 msw dry chamber dives breathing air or enriched air nitrox.

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Harris, RJD, Doolette DJ, Wilkinson DC, Williams DJ. Measurement of fatigue following 18 msw dry chamber dives breathing air or enriched air nitrox. Undersea Hyperb Med 2003; 30(4): 285-291 - Many divers report less fatigue following diving breathing oxygen rich N_2-O_2 mixtures compared with breathing air. In this double blinded, randomized controlled study 11 divers breathed either air or Enriched Air Nitrox 36% (oxygen 36%, nitrogen 64%) during an 18 msw (281 kPa(a)) dry chamber dive for a bottom time of 40 minutes. Two periods of exercise were performed during the dive. Divers were assessed before and after each dive using the Multidimensional Fatigue Inventory-20, a visual analogue scale, Digit Span Tests, Stroop Tests, and Divers Health Survey (DHS). Diving to 18m produced no measurable difference in fatigue, attention levels, ability to concentrate or DHS scores, following dives using either breathing gas.

air, enriched air nitrox, fatigue, chamber dive

Air is the most commonly used breathing gas for shallow underwater diving. Enriched Air Nitrox (EANx: any mixture of nitrogen and oxygen with an oxygen fraction of >0.21) use is becoming widespread within both occupational and recreational diving. Owing to the reduced fraction of inspired nitrogen, the uptake of nitrogen into body tissues during EANx breathing is less than for an air dive of the same depth/time combination. EANx diving therefore allows longer bottom times without an additional decompression requirement. In addition, several unproven properties are attributed to EANx by the diving communities; most common among these is that divers report less fatigue following EANx dives compared with similar air dives (1). In one report of 3500 EANx 32% dives conducted over a 3 month period, the Diving Safety Officer of the Institute of Nautical Archaeology noted that many of the divers reported being less fatigued after surfacing compared to divers breathing air.(2)

Fatigue after diving is likely to be multi-causal, but severe fatigue is a symptom of DCS (3) and moderate fatigue may be a manifestation of decompression stress. If post dive fatigue is reduced by breathing EANx instead of air, this may suggest the presence of a pathological process in otherwise uneventful dives and has implications for both the short term and long term health of compressed air divers.

This double blinded, randomized controlled trial was designed to test the null hypothesis that there is no difference in fatigue following simulated dives (compressed air exposure) of the same depth and duration breathing air compared with EANx.

METHODS

The protocol was approved by the Royal Adelaide Hospital medical research ethics committee. Twelve subjects between the ages of 35 and 45 years, with a recreational diving qualification, and tertiary postgraduate education, were recruited from the authors' acquaintances. This homogenous group was selected in order to decrease the influence of age, intelligence and life experience upon the tests used to assess fatigue and concentration. All subjects were assessed as fit to dive prior to entry into the study.

All simulated dives were performed in the hyperbaric chamber at the Hyperbaric Medicine Unit, Royal Adelaide Hospital. Each subject performed two dives on separate occasions, breathing either air or EANx 36% (36% oxygen–64% nitrogen) in random order. Six divers were present in the chamber for each dive, with three breathing air and three breathing EANx 36%. The subjects were blinded to the identity of the gases. The chamber attendant was also blinded to the breathing gas.

Subjects were asked to refrain from heavy exercise, smoking, SCUBA diving, taking non-prescription drugs and drinking alcohol or caffeinated beverages for the 24 hours before each test dive. The two dives were performed at approximately the same time each day, one week apart, to minimize variability due to circadian rhythms, and any effect of repetitive diving.

The chamber was pressurized with air to 281 kPa(a), equivalent to a depth of 18 msw. Bottom time was 40 min including an 8 to10 min compression, followed by a 15 min linear decompression to the surface (101 kPa(a). The chamber air temperature was maintained at 22-24^{o} C. Subjects breathed through Scott masks with a demand valve. They stepped at rhythmic cadence of 20 steps per minute and step height 20cm (approx 5 METS) for two, five-min periods during the dive.

Fatigue was assessed immediately before and after each dive in two ways. First, subjects rated their perceived level of fatigue using a 100mm visual analogue scale. They also completed the Multidimensional Fatigue Inventory-20 (MFI-20), a survey of 20 questions with Likert scale responses. The MFI-20 is a validated, reliable self-report instrument assessing general fatigue, physical fatigue, mental fatigue, reduced motivation and reduced activity (6). MFI-20 scores were analyzed with respect to the first 3 of these categories and an overall fatigue score.

Attention levels and ability to concentrate were quantified immediately before and after each dive using Digit Span and Stroop tests administered by two of the authors blinded to the breathing gas. For each diver, these tests were administered in the same quiet room, by the same investigator trained to use a standardized technique, at approximately the same time before and after each dive. The Digit Span Forward and Backward tests are part of the Weschler Adult Intelligence Scale (7) and assess of attention and concentration skills, as well as "working memory." It is sensitive to general and focal brain dysfunction (8). The Stroop Test (9) assesses the speed and accuracy of identifying items in three lists: three color names; colored symbols; and the color of the print of a list of color names. The Stroop Test documents information processing speed, inhibition of habitual responses and the maintenance of a course of action despite visual distracters (10).

Subjects completed the Diver Health Survey (DHS) 24 hours after each dive. The DHS is a valid and reliable 10 item inventory of the symptoms of DCI and general health status (11).

Power analysis was based on using the MFI-20 as the primary measure. Literature reports indicate that a difference in score within the MFI-20 sub-scales of 5 points (possible total 20) represents significant fatigue (6, 12). It was calculated that twelve subjects would be sufficient to identify a difference of 5 points in the MFI-20 sub-scales with one-sided significance of 0.05 and 80% power.

The DHS after each dive was analyzed using the paired t-test. The remaining test scores were analyzed using 2-way repeated measure ANOVA with the main effects breathing GAS with two within group levels (air, EANx) and ORDER with two within group levels (before, after). This latter factor allowed examination of a change in test score with the diving exposure as well as any practice effects with repeated application of the tests. A difference in post-dive fatigue ascribable to breathing gas would be identified as a significant interaction between breathing GAS and ORDER. Statistical significance was accepted at $p < 0.05$.

RESULTS

Of the 12 original study subjects, one dropped out after the first dive due to a respiratory infection and was lost from the study. Two other subjects could not perform the second dive at the correct time due to respiratory infections, but performed their second dive 4 weeks later. These results are included in the data analysis.

At no time could the subjects identify the breathing gas. Four subjects complained of noticeable inspiratory resistance during exercise on the breathing circuit supplying air, which was attributed to a relatively low supply pressure. This might have contributed to increased fatigue scores after air diving for these subjects, but no such increase was seen.

No test scores (including the DHS) declined after diving. The main effect ORDER (i.e. before or after the dive) was significant for the color ($P=0.040$) and word-color ($p<0.001$) sub-test of the Stroop test. This was attributed to a marked immediate practice effect whereby subjects had significantly improved performance on repeated testing in the same session. The practice effect did not persist to the next week. The main effect BREATHING GAS (i.e air or EANx) was significant for the mental fatigue sub-scale of the MFI-20 where scores were higher (more fatigued) for air compared with EANx *both before and after diving*. The interaction of breathing gas and order was not significant for any of the tests, indicating no difference in any measures of fatigue between the different breathing gases. The post-dive scores for the two breathing gases for the visual analogue scale, MFI-20 overall score, Digit span tests, and the color and word color components of the Stroop test are shown in Figures 1-3.

DISCUSSION

Since the early days of compressed gas diving, air has been the principle gas employed due to its ready availability. Using EANx, bottom time can be significantly increased compared to diving at the same depth with air, without additional decompression penalty. It is extremely common for divers to claim less fatigue following a dive breathing EANx than they would expect for a similar air dive. In this study following simulated dives controlled for depth, bottom time, decompression rate, temperature, and physical exertion, subjects blinded to breathing gas reported no subjective difference in fatigue (visual analogue scale) breathing air or EANx. In addition there was no difference in fatigue as assessed by the MFI-20 or in the psychometric tests for attention and concentration.

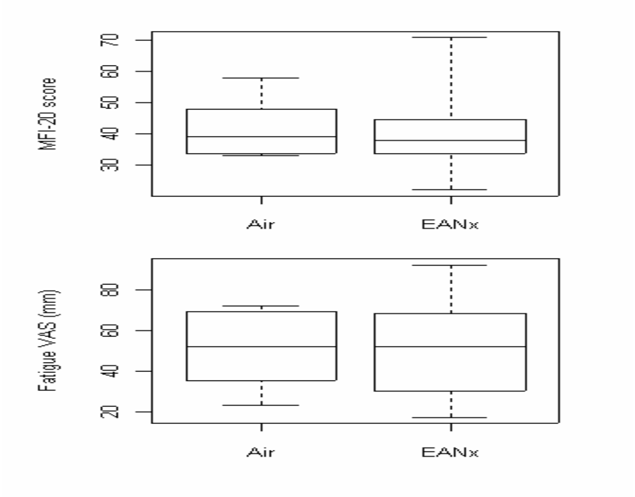
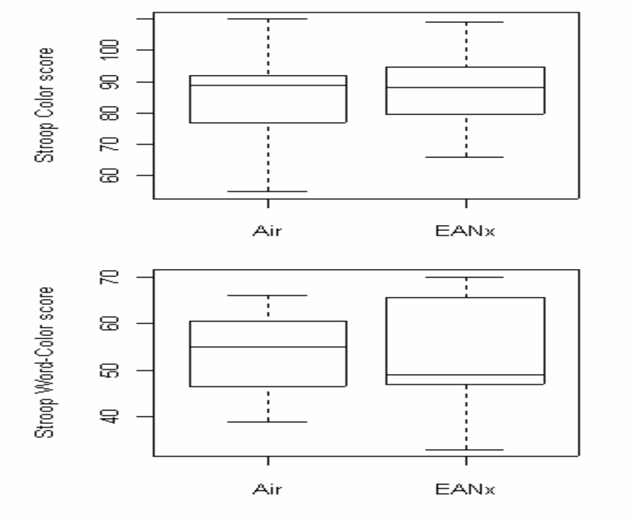


Figure 1. Box plots (median, interquartile range, and extreme values) of the primary measures of fatigue (MFI-20 overall score and Fatigue Visual Analog Scale) following air and EANx dives.

Figure 2. Box plots (median, interquartile range, and extreme values) of the Color and Word-Color components of the Stroop test following air and EANx dives.



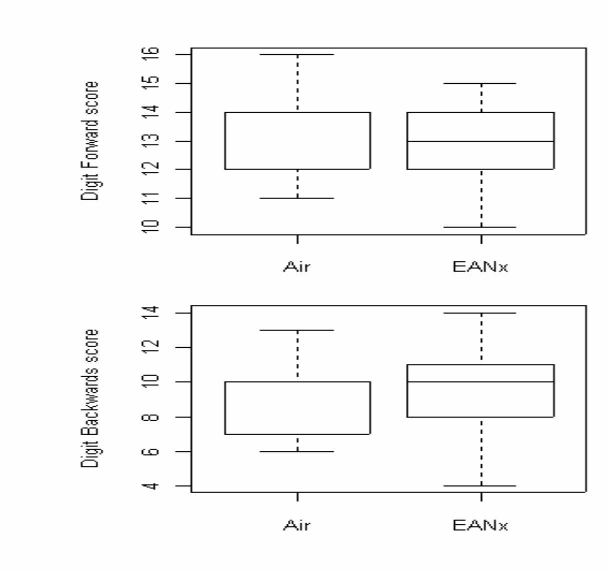


Figure 3. Box plots (median, interquartile range, and extreme values) of the Digit Span test scores following air and EANx dives. Following the air dive the digit forward score median and 25th percentile value were both 12 and the digit backward score median and 75th percentile were both 10.

Visual analogue scales are widely used and validated measures of subjective sensations such as pain and fatigue (13). Reduced fatigue following EANx diving is self-reported by divers; the visual analogue scale should be the ideal tool for quantifying and comparing divers' self-reports of fatigue in this cross-over design study. The MFI-20 is similarly a self-reporting instrument for measurement of fatigue but uses structured questions and responses. Although it has not previously been used in divers, the MFI-20 has been validated for measurement of fatigue following physical activity in healthy subjects (6).

An interesting finding is that the measures of fatigue did not increase following the simulated dives, despite such reports being common following recreational underwater diving. Two likely mechanisms of post dive fatigue are energy expenditure and decompression stress. We believe the work performed during the dive was representative of a typical recreational dive although it may be low compared to some occupational diving. The work performed in this study was sufficient to make the subjects perspire heavily and was perceived as strenuous. In underwater diving, considerable energy is used in maintaining body temperature whereas the study compressed air exposures were much closer to thermoneutral. Although the metabolic demands of recreational SCUBA diving can vary enormously, they have been estimated at 5 – 10 metabolic equivalents (METS) i.e. 5 –10 kcal/kg/hr (4). However, the maximum sustainable swimming speed in diving equipment consumes 1.5L/min of oxygen STPD, which equates to approximately 5 METS, and it unlikely that a typical recreational diver works at this level continuously (5). The exercise protocol was designed to reflect the level of work expected during a recreational dive.

Although the decompression protocol used in this study was not provocative, we believe it was representative of typical recreational diving. As an indicator of decompression stress, the risk of DCS calculated according to the USN93 probabilistic model for air and EANx diving (14) was 1% for the air dives, and 0.36% for the EANx dives. In comparison, mean values of 0.5% have been measured using similar probabilistic models from series of typical occupational (15) and recreational (16) dives. It remains contentious whether dry chamber simulated dives have more or less risk of DCS, although any difference is not great (17). The weight bearing exercise performed in the present protocol may also increase the decompression stress (18). It is possible that anecdotal reports of "sub-clinical" fatigue following recreational diving originate from dives that produce higher than typical decompression stress; we are not aware of any systematic study of this phenomenon.

It is possible these tests may not be appropriate for measuring acute change (before and after the dive). The MFI-20 has not been used in this fashion, and subjects may have remembered and duplicated their pre-dive answers to some extent. Our present findings using the Digit Span and Stroop Tests are consistent with previous reports, where no significant change in test scores was found before and after actual recreational dives in 22 subjects (10). We believe any effect after an uneventful dive that is too small to measure will be clinically irrelevant. It must also be considered that the Stroop and Digit Span tests were insensitive in this study because of the profile of the group. All subjects performed very well on the tests, which may not have been difficult enough in this group to show any effect.

We noted an acute practice effect (improvement in scores caused by repetition) in the Stroop test. Timed performance tests such as the Stroop have been found to be more prone to this effect than are verbal tests like the Digit Span although practice effects have been seen to some extent with both performance and verbal tests when retests are conducted at a variety of intervals

(19, 20). Acute practice effect may have obscured any difference between pre- and post-dive scores. However our study design accounted for any practice effect between dive sessions as the order of gas was randomized. Indeed, although the acute practice effect of the Stroop test was evident in both sessions, it was not maintained between them. The DHS which was administered only once per session, has good retest reliability over this time span (11).

Our present results are at variance with the anecdotal reports of reduced fatigue following EANx dives. Clearly our simulated dives differed in many respects to actual underwater diving, but none of the anecdotal evidence controls for diving exposure and none are blinded. In the one written report we could find (2), the EANx dives had considerably shortened decompression times and therefore total immersion time than previous air dives. Prolonged immersion results in increased energy expenditure due to physical exertion and the metabolic cost of thermoregulation.

In summary, diving to 18m while breathing air produced no measurable difference in fatigue, attention levels, ability to concentrate or DHS scores, compared with EANx 36% in this study.

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