The Implications of SCUBA diving with Air vs. Enriched-Air Nitrox on Mental and Physical Fatigue.

Introduction

SCUBA (Self-Contained Underwater Breathing Apparatus) diving is commonly done using tanks filled with compressed ambient air containing 21% oxygen, 78% nitrogen, and 1% miscellaneous gases. When not SCUBA diving, nitrogen passes harmlessly through a person's blood stream. When nitrogen is inhaled at depth, the higher pressure causes more nitrogen to diffuse into the blood stream and various body tissues. Then, after returning to lower pressure at the surface, nitrogen gas dissolved in tissues diffuses and forms bubbles in the bloodstream, which eventually off gas and escape the body through normal exhalation or, in extreme cases, can expand to block blood flow or burst the vessel (1). The blockages or bursts result in symptoms like joint or muscular pain, headaches, dizziness, fatigue, and many others. This serious medical issue is known as decompression sickness (DCS).

The formation of nitrogen bubbles in the bloodstream, along with other factors, is thought to induce fatigue. By decreasing the amount of nitrogen absorbed, divers could possibly experience less fatigue and reduce the likelihood of DCS (2). The most common way to achieve this is enriched-air nitrox (EAN) diving where a diver uses a gas mixture that has an increased oxygen composition and decreased nitrogen composition. While many experienced SCUBA divers claim that EAN diving reduces post-dive fatigue, the few studies testing the impact of breathing EAN on post-dive fatigue either did not document an effort to hide the gas composition from the subjects, which would allow for a placebo effect, (3) or the study conducted dry dives using a compression chamber which removes contributing factors like temperature and physical exertion felt on an actual dive (4).

This study aims to find whether the reported extra benefits of EAN are due to the physical impact of the gas composition or a placebo effect that has permeated the SCUBA diving community. This is done by having SCUBA divers breathe either a standard air mixture or a mixture of EAN and monitoring the diver's physical ability and mental awareness before and after the dive. Analog self-evaluation surveys are also given pre- and post-dive primarily to track subjective feelings of pain and gauge whether divers could consistently decipher what gas mixture they were breathing based on previous experience.

Methods & Materials

All testing was done at Blue Grotto Springs in Williston, FL with an average water temperature of 72 degrees Fahrenheit. This dive site was chosen because it is a spring, so it has the same water temperature all year, has little to no current, and a singular point of entry ensuring the physical exertion of the divers was standardized. All divers drank 24 oz of water the night before and an additional 24 oz the morning of the dive. Participants who had a later dive time were told to maintain hydration levels by sipping water until it was their time to dive. Verbal conformation from all divers was obtained to ensure they had properly hydrated. All participants had similar dive gear with demand valves on a comfortable setting, so breathing was not impaired. All gear had been serviced in the past year by a qualified technician according to manufacturer standards. Every dive group had a divemaster who was not participating in the study with them to ensure participant safety, to ensure proper depths and times were achieved for the dive, and to report any deviations from the standardized dive plan. Dive participants ranged in age from 13 to 18 years-old.

In order to eliminate a placebo effect, the tanks were covered to hide the sticker that marks an EAN tank. However, it is a common safety practice that divers analyze their own nitrox tank before a dive to determine its contents and the Maximum Operation Depth (MOD), or depth restriction the increased oxygen percentage creates, so it is important that this safety measure was incorporated since the diving was done by minors. To create a blind study that still included this safety practice, participants analyzed a nitrox tank before their dive and created two labels with their initials, MOD, and oxygen percentage. One label was then placed on the nitrox tank and the other was placed on a tank cover made from black opaque yoga pant legs. The tank the participant analyzed was then obscured from the view of all participants and a coin was flipped to determine if the participant would get the nitrox tank they analyzed or a standard air tank. The randomly selected tank then had the diver's corresponding tank cover placed on it and secured with zip ties to ensure no tank markings could be seen. All tanks were identical in size, color and weight, and had identical valves and no identifiable accessories. Each prepared tank with covers on were returned to the participants so they could set up their gear. All participants were monitored to ensure no one tampered with the tank cover. All tanks not in use were hidden from study participants.

Upon arrival at the dive site, divers performed three pre-dive counter movement jump (CMJ) tests (5) (see Appendix A) to measure pre-dive physical fatigue and a self-evaluation survey (see Appendix B). The self-evaluation survey recorded the age, gender, diving experience, sleep quantity and quality, and intake of caffeine and food as well as recorded on an analog scale from 1-10 the participants perception of their mental and physical fatigue. Electroencephalogram (EEG) tests were administered 30-60 minutes before the dive to measure pre-dive mental fatigue. The EEG used was a WAVI make and ran a P300 sports protocol.

All 15 participants were put into dive groups with one divemaster who was not participating in the study and 1-2 participants. Dive times averaged 32 minutes with a standard deviation (SD) of 3.7 minutes which included a three-minute safety stop at 15 ft. Dive depths averaged 56.5 feet with a SD of 3.6 feet with an ascent rate of 30 ft per minute. During the dives, participants built small rock piles or observed wildlife but did not engage in strenuous activity. Post-dive CMJ tests and the initial post-dive self-evaluation surveys were taken within minutes of the participants surfacing. Post-dive EEG's were conducted 40-60 minutes post-dive, which is around the same time as peak bubble count for the bloodstream (the time at which the most amount of nitrogen gas bubbles are present in the bloodstream). Divers then stayed on site to complete 60- and 120-minute post-dive self-evaluation surveys.

Results

Due to machine error, the EEG did not record all needed numbers for participants. If a participant did not have a data point after both of their air and nitrox dive for a section of the EEG (e.g. physical reaction time, trail making test A, trail making test B, etc.) that diver was excluded from data analysis for that section only.

Averages and sample (SD) were obtained for all dive profile metrics, EEG sections, and CMJ data. These can be seen in Table 1.

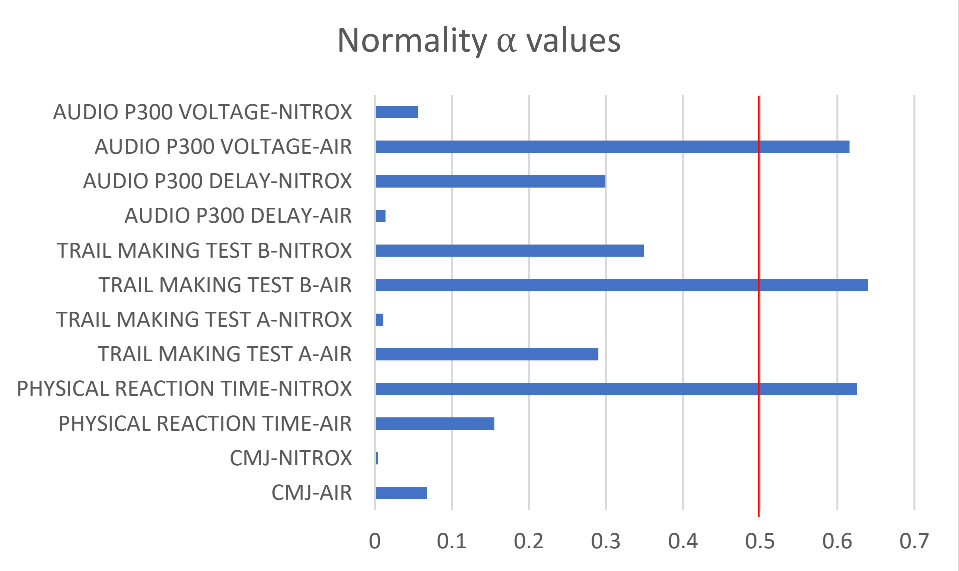
Table 1 Average and sample standard deviation for dive time, dive depth, and empirical tests

Data	Average	Sample SD
Dive Times (min)	32.07	3.74
Dive Depth (ft)	56.50	3.60
CMJ: air (m)	0.03	0.04
CMJ: nitrox (m)	0.03	0.04
Physical Reaction time: air (ms)	-6	18.87
Physical Reaction time: nitrox (ms)	-8.43	13.54
Trail Making test A: air (sec)	4.22	15..29
Trail Making test A: nitrox (sec)	4.67	12.72
Trail Making test B: air (sec)	9.44	21.03

Trail Making test B: nitrox (sec)	19.2	31.51
Audio P300 Delay: air (ms)	-101.33	154.87
Audio P300 Delay: nitrox (ms)	21.33	249.40
Audio P300 Voltage: air (μV)	1.19	1.59
Audio P300 Voltage: nitrox (μV)	-0.45	0.80

The Shapiro-Wilk normality test was conducted on post-dive EEG and CMJ data. Post-dive data from nitrox and air dives were kept separate for this test. If either post-dive data for air or nitrox dives was non-parametric, then a non-parametric test was used on both the air and nitrox post-dive values.

Fig. 1 α-values for normality test where any value greater than 0.5 is non-parametric



For normally distributed data, a paired sample t-test for the mean was performed.

Table 2 Paired sample t-test critical values and p-stats for all parametric data. All values were rounded to two decimal places.

Data	Critical-Value	P-stat	Result
Physical Reaction Time	2.45	0.75	Fail to Reject the null
Trail Making Test B	2.31	0.54	Fail to Reject the null
Audio P300 Voltage	2.45	0.39	Fail to Reject the null

For non-parametric data the significance of the difference between paired samples (ambient air and nitrox) was tested using a median resampling method (6).

Table 3 Total percent of null hypothesis medians above and below the positive and negative sample median for non-parametric data. Percents less than 0.05 allow us to reject the null hypothesis.

Data	Total Percent	Result
CMJ	0.677	Fail to Reject the null
Trail Making Test A	0.868	Fail to Reject the null
Audio P300 Delay	0.908	Fail to Reject the null

Self-evaluation surveys showed that when participants were asked, at the end of all testing, what gas mixture had been provided for their dive, 60% of air divers correctly identified their gas mixture and only 40% of EAN divers correctly identified their gas mixture. The averages of each self-evaluation survey section were taken, except physical energy due to editing error, and the difference between air and nitrox averages was taken.

Table 4 Self-reported differences between air and nitrox survey averages before, directly after, 60 minutes after, and 120 minutes after the dive. Positive numbers indicate a reported improvement in the measurement and negative numbers indicate a reported decline in the measurement.

Difference between air and EAN	Mental Fatigue	Headache	Body Ache
Pre-dive	0.78	0.17	0.77
Immediate post-dive	0.29	1.21	0.36
60-min post-dive	-0.14	1.13	0.35
120-min post-dive	0.5	0.79	0.79

Discussion

All statistical tests resulted in a failure to reject the null hypothesis implying there is not a significant difference between using EAN and standard air in regard to post-dive physical and mental fatigue. The reason for this could be the slow build up and release of the nitrogen is not enough to physically impact physical fatigue and mental awareness post-dive. The reason for the common idea that nitrox results in a general “better” feeling post-dive might then be the impact of a third factor like the psychological, and potentially therapeutic, impact of the brain processing information slower under the increased atmospheric pressure with a greater amount of oxygen. However, these results come with a substantial amount of variation as shown by the large SD for many of the averages. This variation most likely comes from the small sample size with some measurements having at most 12 usable data sets and as little as 6. With these sample sizes, things like an especially cold morning or rainy weather probably had a larger impact on the data than it should have. Hopefully, those variations were mitigated by half the participants being on air and the other half being on nitrox each day. There was also likely unintentional variation during the EEG probably had a significant impact. For example, if the participant did not fully understand the tests or if different administrators of the test explained it differently.

The self-evaluation surveys show that, on average, people reported less mental fatigue, headache, and body ache after diving on EAN when compared to air. However, participants also seemed to be experiencing these physical symptoms less severely before the nitrox dives and more severely before the air dives. This could mean participants randomly felt better in general on the days they did their EAN dive.

Other sources had different methodologies which lead to very different conclusions than the one above. Lafère et. al (3) used a visual analog scale to measure perceived fatigue and critical flicker fusion frequency (CFFF) to test mental reflex and awareness before and after and open water dive. While they had a large sample size of 219 adults, they split their group into using either air or EAN and let the divers know what gas they were diving on. They found post-fatigue was greater in the air group than the nitrox group using CFFF and the visual analog scale. However, this could have been be due to the nitrox group being in better shape than the air group or a placebo effect. The diving groups also had a high probability of having varying conditions since the dives took place in the ocean which has highly volatile changes in current and temperature compared to the standardized environment used in this study.

Another study (4), also lookied at diving fatigue when using air vs. EAN and found the nitrox group showed less fatigue than the air group. However, this study had a smaller sample size of 8, with those 8 doing one dive on air and one on EAN, and they did dry dives where participants sat in a compression chamber and were not exposed to any physical factors that SCUBA divers experience. Thus, their conclusion makes sense since breathing a higher percent of oxygen does increase brain function however this cannot be applied to real world diving because it does not factor in the mental and physical stress of being under water in the elements.

For future research all participants should perform their dives in a spring or pool where condition can be kept as consistent as possible while still exerting the pressures of real-world diving. Participants should also never know what gas they were diving on and the assignment of a gas should be random on any given day so that all participants diving on the same gas are not all diving together. Also, a larger sample size should be used in all research moving forward to mitigate and random deviations or inconsistencies. Some simpler things to mitigate inconsistences would be to standardize exposure protection so some participants don't experience the extra stress of being cold and all participants should use medication or a topical treatment so that no one has varying dive time due to taking longer to clear their ears on descent. Having participants also do multiple dives in a day on the same gas could yield more consistent results since that would increase the fatigue and nitrogen loading which could provide a larger difference between diving on air vs. EAN.

Conclusion

When following a methodology that is as close to real-world diving as possible and eliminating any placebo effect by blinding participants to what gas they are diving on it seems that there is no significant difference in fatigue when diving with air or EAN. However, further research must be done with larger sample sizes. The implication of this conclusion is that while EAN does provide longer bottom times at deeper depths, when diving in shallow water, air is just as preferable as EAN in terms of post-dive fatigue since there seem to be no extra benefits to EAN.

Literature Cited

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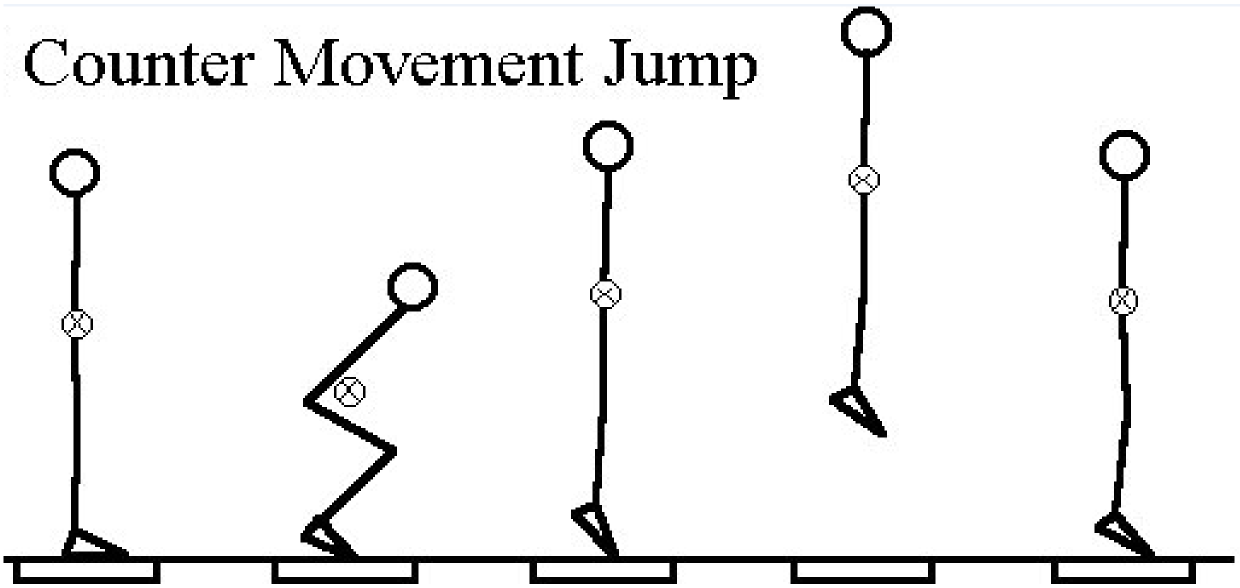
Appendix A: Counter Movement Jump test

All participants will be instructed how to jump in a uniform way which is shown below. The jumps will be made by squatting to a depth of 5 inches and then making the jump shown below without arm swing.



<u>Appendix B:</u> Self-Evaluation Survey

Date: ___/___/______

<u>Diver information</u>

Diver name: ______________________________ Age: ______Gender: _____________
Tank number: _____

Approximate number of life time dives: _____ Approximate number of nitrox dives: _____

Highest certification level (open-water, advanced, dive pro, etc.): ________________

Please approximate the amount of caffeine consumed: ______________________________

Please list approximately how many hours of sleep you got and quality (1-I am napping right now, 10-fully rested and rearing to go)

Hours of sleep:	1-2	2-3	3-4	4-5	5-6	6-7	7-8	+8		
Quality:	1	2	3	4	5	6	7	8	9	10

How much/what have you eaten today?

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Did you work out before arriving? If so, please describe the intensity.

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____

<u>Before dive evaluation</u>

Time taken: ________ am/pm

Please rate the following on a scale of 1-10

(1- I could run a mile, 10- Walking is too tiring)
Physical Energy: 1 2 3 4 5 6 7 8 9 10

(1- I could solve any problem, 10- It is hard to do basic math)
Mental Fatigue: 1 2 3 4 5 6 7 8 9 10

(1- No headache, 10-Someone hit me with a hammer)
Headache: 1 2 3 4 5 6 7 8 9 10

(1- None, 10- My whole body is very sore)

Body aches:	1	2	3	4	5	6	7	8	9	10

Other temporary discomforts if any (please specify below):

________________	1	2	3	4	5	6	7	8	9	10
________________	1	2	3	4	5	6	7	8	9	10
________________	1	2	3	4	5	6	7	8	9	10

Immediate After dive evaluation

Time taken: _________ am/pm

PSI used: ___________

Please rate the following on a scale of 1-10

(1- I could run a mile, 10- Walking is too tiring)

Physical Energy:	1	2	3	4	5	6	7	8	9	10

(1- I could solve any problem, 10- It is hard to do basic math)

Mental Fatigue:	1	2	3	4	5	6	7	8	9	10

(1- No headache, 10-Someone hit me with a hammer)

Headache:	1	2	3	4	5	6	7	8	9	10

(1- None, 10- My whole body is very sore)

Body aches:	1	2	3	4	5	6	7	8	9	10

Other temporary discomforts if any (please specify below):

________________	1	2	3	4	5	6	7	8	9	10
________________	1	2	3	4	5	6	7	8	9	10
________________	1	2	3	4	5	6	7	8	9	10

60-minite After dive evaluation

Time taken: _________ am/pm

Please rate the following on a scale of 1-10

(1- I could run a mile, 10- Walking is too tiring)
Physical Energy: 1 2 3 4 5 6 7 8 9 10

(1- I could solve any problem, 10- It is hard to do basic math)
Mental Fatigue: 1 2 3 4 5 6 7 8 9 10

(1- No headache, 10-Someone hit me with a hammer)
Headache: 1 2 3 4 5 6 7 8 9 10

(1- None, 10- My whole body is very sore)
Body aches: 1 2 3 4 5 6 7 8 9 10

Other temporary discomforts if any (please specify below):

________________ 1 2 3 4 5 6 7 8 9 10

________________ 1 2 3 4 5 6 7 8 9 10

________________ 1 2 3 4 5 6 7 8 9 10

2-Hour After Dive Evaluation

Time taken: ________ am/pm

Please rate the following on a scale of 1-10

(1- I could run a mile, 10- Walking is too tiring)
Physical Energy: 1 2 3 4 5 6 7 8 9 10

(1- I could solve any problem, 10- It is hard to do basic math)
Mental Fatigue: 1 2 3 4 5 6 7 8 9 10

(1- No headache, 10-Someone hit me with a hammer)
Headache: 1 2 3 4 5 6 7 8 9 10

(1- None, 10- My whole body is very sore)
Body aches: 1 2 3 4 5 6 7 8 9 10

Other temporary discomforts if any (please specify below):

________________ 1 2 3 4 5 6 7 8 9 10

________________	1	2	3	4	5	6	7	8	9	10
________________	1	2	3	4	5	6	7	8	9	10

If you were to say how certain you are (1being no idea, 5 being absolutely certain) about the gas composition of your tank, how certain are you that is was…

Air (21% Oxygen):	1	2	3	4	5
Nitrox (40% Oxygen):	1	2	3	4	5

Please describe any other general sensations you had during the dive.

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