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Measurement of Fatigue following 18 msw Open Water Dives Breathing Air or EAN36

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Abstract

SCUBA divers often report feeling fatigued upon conclusion of diving activities. Post-dive fatigue is thought to be induced by increased energy demands of submersion in a hyperbaric environment and decompression stress. Anecdotal reports indicate a reduction in post-dive fatigue when using enriched-air nitrox (EAN). The purpose of this double-blind study was to compare subjective fatigue levels experienced by SCUBA divers after two repetitive air dives and two repetitive EAN36 dives on separate, nonconsecutive days. Eleven male participants completed pre- and post-dive fatigue assessment using the Multidimensional Fatigue Inventory and a Visual Analogue Scale, while general health was assessed using the Diver Health Survey. Divers did tend to be more fatigued after diving; however, breathing gas mixture exhibited no statistically significant effect. Participants did have significantly lower Diver Health Survey scores upon the conclusion of EAN36 test sessions, possibly indicative of reduced decompression stress.

Keywords: decompression stress, nitrox, post-dive fatigue, SCUBA

Introduction

Many SCUBA divers use a breathing gas mixture, enriched-air nitrox (EAN), which contains a higher percentage of oxygen and lower percentage of nitrogen compared to air (20.93% O_2, 78.08% N_2). Since nitrogen is inert in metabolic respiration, lowering the fraction of nitrogen in a SCUBA diver's breathing gas effectively reduces the relative decompression stress experienced when compared to an air dive of similar depth and duration. The two most common EAN mixes contain 32% or 36% oxygen, denoted as EAN32 and EAN36. These have been established as standard EAN mixes in the National Oceanic and Atmospheric Administration Dive Manual and are often available from retail dive shops (Joiner, 2001).

Anecdotal reporting suggests that breathing EAN during a dive helps reduce post-dive fatigue (Charlton, 1998; Lang, 2001). The mechanism by which this may occur is not clearly understood; however, it has been purported that post-dive fatigue might be a result of decompression stress (Lang, 2001). Under this assumption, reducing inert gas levels in a breathing mixture reduces decompression stress as relatively lower concentrations of inert gas are absorbed and eliminated throughout the course of a dive. A diver would, thereby, surface with a noticeable reduction in post-dive fatigue. The only known study to test this premise found no significant difference between fatigue levels following air and EAN dives (Harris et al., 2003). Harris et al. acknowledged that the single, dry chamber dive profile used in their study may not have induced enough decompression stress to observe a difference between air and EAN36 post-dive fatigue levels.

It is known that greater levels of decompression stress are experienced during repetitive dive profiles due to incomplete equilibration toward normobaric inert gas saturation between dives (Marroni et al., 2000). Open water environments elicit increased energy costs of repetitive SCUBA dives; specifically, adaptations to thermoregulatory demands that would be difficult to simulate in a dry chamber. If decompression stress is associated with post-dive fatigue, assessment following repetitive dives in an open water environment may provide the combined stimuli to produce a significant difference between air and EAN post-dive fatigue.

The purpose of this double-blind study was to compare subjective fatigue levels experienced by SCUBA divers after two repetitive air dives and two repetitive EAN36 dives on separate, nonconsecutive days. The open water environment and repetitive dive profile required increased energy expenditure and decompression stress relative to a single, dry chamber dive, thereby creating a potential for increased differentiation between post-dive fatigue levels following air and EAN dives.

Methods

Participants

Eleven certified male SCUBA divers, aged 18-35 years, volunteered to participate in two test sessions separated by a minimum of 48 h. Separating test sessions in this manner minimized any effect related to multiday diving. Participants had active cold water dive experience and a minimum of 12 dives in the past year, ensuring they were accustomed to the thermoregulatory demands and the need for adequate thermal protection (typically a 7 mm wetsuit or drysuit). The minimum 12 dive requirement was consistent with active diving standards established in scientific diving manuals (American Academy of Underwater Sciences [AAUS], 2006). In addition, participants were certified as either AAUS scientific divers or dive leaders (i.e., Divemaster, Assistant Instructor, or Instructor) from nationally recognized dive agencies. Individuals meeting these qualifications have experience with task-related dive protocols requiring mastery of buoyancy control. The specified age range was selected to minimize risk of age-related health complications. The number of participants was deemed appropriate based on similar methods used by Harris et al. (2003). Females were excluded from this study to control for potential variability related to decompression incidence and the menstrual cycle (Lee et al., 2003).

Instrumentation

Fatigue was assessed using the Multidimensional Fatigue Inventory (MFI-20) and a 100 mm Visual Analogue Scale (VAS). The MFI-20 is a 20 item questionnaire consisting of five subscales measuring different aspects of fatigue. It is a validated tool that has been used to evaluate fatigue after SCUBA diving and physical activity (Smets et al., 1995; Harris et al., 2003). In an effort to direct participant responses to acute fatigue levels, the instruction set of the MFI-20 was modified slightly; participants were asked to view questions in terms of how they were feeling "right now" instead of how they had been feeling "lately." The VAS is a reliable tool for measuring general fatigue and has been utilized to compare pre- and post-dive fatigue levels (Grant et al., 1999; Harris et al., 2003). Perceived workload and thermal comfort were measured using a subset of questions from the Diver's Alert Network Project Dive Exploration questionnaire. The Diver Health Survey (DHS) was used to monitor a participant's general wellbeing after a test session. The DHS has been validated for assessing general symptoms indicative of decompression illness (Doolette, 2000).

Participants provided their own primary and backup regulator, submersible pressure gauge (SPG), compass, timing device, and depth gauge or computer. Cochran DDR-200 data recorders were attached to each diver to document depth, temperature, dive time, and ascent rates. Dive teams were provided a waterproof slate with the dive plan written on it, and two SCUBA cylinders containing either air or EAN36. All other dive equipment, including appropriate thermal protection (7 mm wetsuit or drysuit), was provided by participants. Participants were required to use the same gear configuration for all dives.

Professional Association of Dive Instructors repetitive air dive tables and National Association of Underwater Instructors EAN36 dive tables were utilized to design safe dive profiles. A 20 m transect tape was used to mark a fixed underwater course along an 18 msw depth contour. Test session data consisting of start and end times, surface interval time, beginning and ending cylinder pressure, and cylinder test set designator were recorded for each dive.

Procedures

The methods employed in this study were approved by an Institutional Review Board in accord with the ethical principles for research involving human subjects at San Jose State University. Participants were informed that they were being asked to participate in an underwater research project assessing post-dive fatigue levels after breathing either air or EAN36. Inherent risks and potential benefits of this study were discussed in detail with each participant. Participants read and signed a consent form. In the unlikely event of a diving accident, a certified Diving Medical Technician was available for consult during all test sessions.

Participants completed two test sessions separated by a minimum of 48 h. The test sessions occurred at approximately the same time each day to maintain consistent sleeping patterns and to avoid offsetting circadian rhythms. Participants were asked to refrain from heavy exercise, smoking, SCUBA diving, nonprescription drugs, and drinking alcohol or caffeinated beverages for 24 h prior to testing.

Prior to the beginning of a test session, environmental assessments were made to determine whether ocean conditions were safe. Participant feedback was part of the assessment; both the researcher and participant could cancel a test session if either individual felt conditions were hazardous. Swell height and period, wind speed and direction, and water craft advisory data were retrieved the morning of each test session from the National Weather Service Coastal Waters Forecast for Monterey Bay, California.

At the beginning of each test session, fatigue was assessed using the MFI-20 and VAS, in random order. Participants completed tests in a quiet environment to minimize distractions from other divers. After pretests were completed, test session dive plans were discussed, with participants informed that they would be breathing either air or EAN36 for two repetitive dives. The oxygen fraction of 0.36 was selected to provide the largest differential between oxygen concentrations of common EAN mixes and air. Both participant and researcher were unaware of which test session utilized EAN36. Decompression and oxygen loading parameters were analyzed for both breathing mixtures to ensure participants of safe dive profiles that fell within recommended no-decompression stop limits. Underwater signals and safety protocols were discussed in detail.

A test session dive plan consisted of two, 30 min square profile dives at a depth of 18 msw, separated by a one hour surface interval. Participants dived in teams of two, maintaining close proximity (within 1 m of each other). Either participant could abort a dive at any time for any reason. If divers became separated at depth, they were to stop and search for each other for 1 min. If they were unable to reconnect underwater, the divers were to ascend at a rate of 9 m/min and reconvene at the surface.

Participants were transported by motor boat to the test site. Prior to all test session dives, beginning cylinder pressure was recorded. Dive teams descended down a fixed line. Descent rate was controlled by the participants' ability to equalize pressure in their ears. The descent was expected to take approximately 1 min. Participants swam laps along a 20 m transect tape at a depth of 18 msw. A Timex Expedition digital watch was used to monitor and maintain a swimming rate of 18.29 $m \cdot min^{-1}$. Dujić et al. (2005) used a similar rate of 17 m/min to assess the effects of low intensity underwater exercise (approximate oxygen consumption rate of 13 $mL \cdot kg^{-1} \cdot min^{-1}$) on decompression stress in fit divers. Participants were to begin an ascent at a rate of 9 $m \cdot min^{-1}$ when their total bottom time reached 25 min. If a problem occurred or a dive team member's SPG read 700 psi (49.2 $kg \cdot cm^{-2}$) or lower, participants were instructed to abort the test protocol and ascend safely. Dive teams conducted a 3 min safety stop at 5 msw, and then proceeded to the surface at a rate of 9 $m \cdot min^{-1}$. The total ascent time including safety stop was 5 min. Dive time, maximum depth, ending cylinder pressure, and water temperature were recorded. Participants prepared dive gear for a second dive, completed a questionnaire rating perceived workload and thermal comfort, reported problems experienced, if any, and then rested for the remainder of the surface interval. Water, granola bars, bagels, yogurt, and bananas were available at each test session. Participants were not required to consume these items, but were asked to be consistent in snack choice between test sessions. The second dive followed the same protocol as the first.

Upon conclusion of the second dive, participants were instructed to refrain from heavy exercise, smoking, additional SCUBA dives, nonprescription drugs, alcohol consumption, caffeinated beverages, and napping for 90 min. After 90 min, participants were asked to complete the MFI-20 and VAS. The 90 min post-dive interval for fatigue assessment was implemented in an effort to account for continued decompression stress beyond the duration of the actual dive (Radermacher et al., 1990; Marroni et al., 2000). A test session concluded with participants completing the DHS 24 h after the second dive.

Cylinders were filled by a designated, certified, compressed gas fill station operator. The fill station operator was provided four balanced, randomized templates specifying gas order for each participant. One template was randomly selected by the fill station operator to be used throughout the study. Participants and researcher did not know which template was used. A participant ID was assigned and recorded on the fill template to ensure each participant received both treatments. Cylinder fill pressure and percentage of oxygen were recorded on a spreadsheet. All EAN36 fills contained between 35-37% O_2.

Statistical Analyses

The independent variable in this study was breathing gas (air or EAN36). The dependent variables were fatigue, workload, and thermal comfort. The general fatigue (GF), physical fatigue (PF), and mental fatigue (MF) subscales of the MFI-20 were scored. Distance from the 'no fatigue' anchor to the participant's subjective fatigue marking on the VAS was measured to the nearest millimeter. The effect of breathing gas on post-dive fatigue levels was analyzed using a two-way repeated measures analysis of variance (ANOVA). A paired t-test was performed to examine DHS responses. Pearson product-moment correlations were used to examine relationships between breathing gas volume consumed, thermal comfort, workload, temperature, and swimming speed. A paired t-test was used to assess perceived workload relative to breathing gas treatment. Sigma Stat version 3.5 (Systat Software, Inc.) was used for all statistical analyses. Dive profile data were acquired using Professional Analyst 4.01 (Cochran Consulting, Inc.).

Results

Eleven participants completed two test sessions with minimal complications. Three test sessions were cancelled and rescheduled due to unsuitable diving conditions (e.g., strong currents, large swell); mechanical issues with the motor boat led to the rescheduling of another. No other test sessions were cancelled or aborted. The average interval between test sessions for participants was 25 ± 5 days, mean (*M*) ± standard error of mean (*SEM*). Seven days was the minimum; 148 days was the maximum. No equipment problems were reported; however, one participant's data recorder failed during a test session, yielding irretrievable dive profile information. For this case, the individual's profile was based on the second team member's data recorder. Descriptive data for test session dive profiles are outlined in Table 1.

Table 1. Test Session Dive Profiles

	Water Temperature (ºC)	Depth (m)	Time Underwater (min)	Time Swimming (min)	Speed ($m\cdot min^{-1}$)	Distance Swam (m)	Gas Used (L)
M	12.0	17.3	30.2	21.1	17.2	362.5	1626.7
SEM	0.2	0.1	0.3	0.3	0.2	7.0	30.9

Note. Values are means (*M*) ± standard error of the mean (*SEM*). Distance does not include descent, ascent, or movement during safety stops.

Figure 1 shows the expected dive profile and an actual profile retrieved from a data recorder. The descent and ascent rates were 15 ± 0.4 $m\cdot min^{-1}$ and 6.7 ± 0.2 $m\cdot min^{-1}$ (*M* ± *SEM*), respectively. These were slightly slower than the prescribed rates.

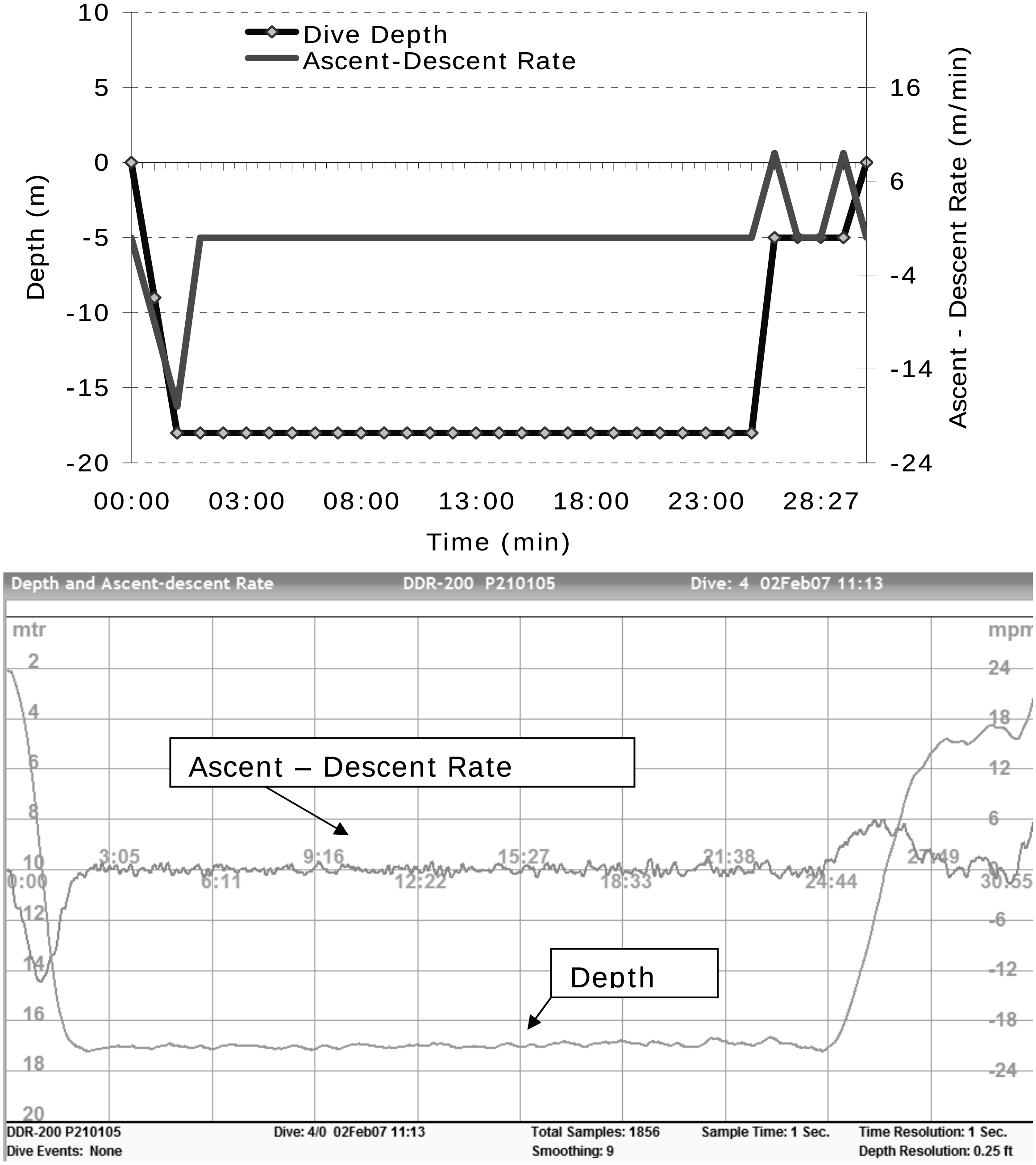

Figure 1. Planned profile (top) and actual data retrieved from the Cochran DDR-200 (bottom).

Visual Analogue Scale

There were no statistically significant differences between breathing air or EAN36 on fatigue ratings (30.8 ± 3.7 vs. 34.7 ± 4.6 mm, $p>0.05$). Although not statistically significant, post-dive fatigue levels, 39.2 ± 4.3 mm, tended to be greater than pre-dive ratings, 26.4 ± 3.6 mm (*M* ± *SEM*), independent of breathing gas mixture ($F_{1,\ 10} = 4.675$, p=0.056). There was no statistically significant interaction between breathing gas mixture and pre- and post-dive fatigue ratings.

MFI-20

There were no statistically significant differences between breathing air or EAN36 on fatigue ratings. There were statistically significant differences in post-dive fatigue compared to pre-dive ratings, independent of gas mixture, for the GF ($F_{1, 10}$ = 6.115, p=0.033) and MF ($F_{1, 10}$ = 11.658, p=0.007) subscales. The PF scores did not yield a statistically significant result when comparing pre- and post-dive fatigue ratings (see Figure 2). There were no significant interactions between breathing gas mixture and pre- and post-dive fatigue ratings. ANOVA data are summarized in Table 2.

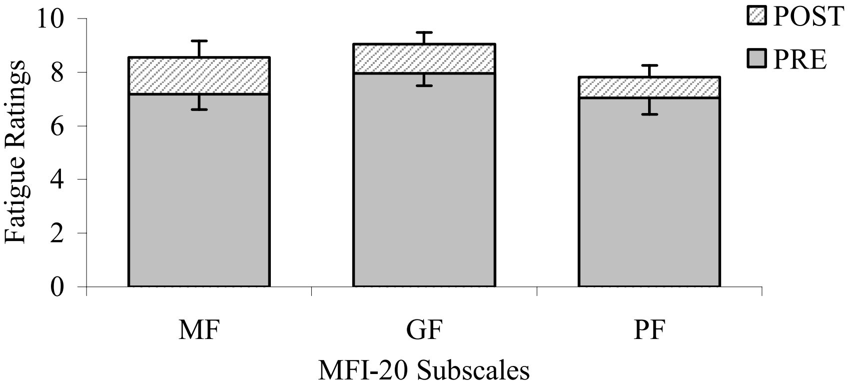

Figure 2. Least squares mean fatigue responses for mental fatigue (MF), general fatigue (GF), and physical fatigue (PF) subscales of the MFI-20 pre- and post-dive, independent of breathing gas mixture.

Table 2. MFI-20 Two-Way Repeated Measures ANOVA summary

Subscale	Source of Variation	df	SS	MS	F	p
MF	Participant	10	216.182	21.618		
	Factor A	1	20.455	20.455	11.658	0.007
	Factor A x Participant	10	17.545	1.755		
	Factor B	1	0.091	0.091	0.012	0.914
	Factor B x Participant	10	74.909	7.491		
	Factor A x Factor B	1	4.455	4.455	2.279	0.162
GF	Participant	10	101.500	10.150		
	Factor A	1	13.091	13.091	6.115	0.033
	Factor A x Participant	10	21.409	2.141		
	Factor B	1	0.364	0.364	0.117	0.740
	Factor B x Participant	10	31.136	3.114		
	Factor A x Factor B	1	0.818	2.668	0.307	0.592
PF	Participant	10	166.045	16.605		
	Factor A	1	6.568	6.568	1.101	0.319
	Factor A x Participant	10	59.682	5.968		
	Factor B	1	6.568	6.568	3.029	0.112
	Factor B x Participant	10	21.682	2.168		
	Factor A x Factor B	1	0.205	0.205	0.102	0.756

Note. MF is mental fatigue, GF is general fatigue, and PF is physical fatigue. Factor A is time of test (PRE or POST); Factor B is breathing gas (AIR or EAN).

Post-Dive Health Analysis

Diver Health Survey responses were evaluated after each test session to determine if participants were experiencing signs or symptoms of decompression sickness. One participant did not submit a DHS after his second test session. Although no responses warranted further inquiry into a participant's post-test health, a paired t-test yielded a significant difference between air and EAN36 posttest responses (t = 2.60, p=0.032). The mean scores for air and EAN36 test sessions were 2.89 ± 0.68 and 1.44 ± 0.29 (*M* ± *SEM*), respectively (both considered low risk for developing health complications from a previous day's dive—30 was the maximum possible score).

Environment and Workload Analyses

Thermal comfort was rated on a scale of 1 (cold) to 5 (warm), and workload was rated 1 (light) to 5 (hard). Table 3 shows the Pearson product-moment correlation coefficients between these variables. Small, positive correlations were found between gas consumed and workload (r = 0.320 p=0.034) and thermal comfort and water temperature (r = 0.404, p=0.007). No other statistically significant correlations were found. No significant difference was found in perceived workload relative to breathing gas treatment (t = 1.678, p=0.108).

Table 3. Pearson Product-Moment Correlation Coefficients

	Thermal Comfort	Workload	Temperature	Swimming Speed
Gas Consumed	-0.198 p=0.198	0.320 p=0.034	-0.087 p=0.573	0.174 p=0.259
Thermal Comfort		0.076 p=0.622	0.404 p=.007	-0.073 p=0.673
Workload			-0.118 p=0.447	0.185 p=0.229
Temperature				-0.029 p=0.851

Note. Gas consumed was measured in psi, temperature in ºC, and swimming speed in m/min. Thermal comfort was rated on a scale of 1 (cold) to 5 (warm), and workload was rated from 1 (light) to 5 (hard). Samples = 44 (11 participants, two test sessions, two dives each).

Results from the subjective fatigue tests showed that divers were fatigued following repetitive SCUBA dives. The data did not indicate reduced fatigue following EAN36 dives compared to air dives of similar depth and duration. Scored responses for the DHS were significantly higher following air dives compared to EAN dives. Divers breathed more gas during dives with higher perceived workloads and reported more thermal discomfort when the water temperature was colder.

Discussion

The purpose of this study was to compare fatigue levels between two test sessions consisting of two repetitive dives breathing either air or EAN36 in an open water environment. It was hypothesized that the reduced nitrogen level and subsequent higher oxygen levels would lead to decreased fatigue following two repetitive EAN36 dives. Analyses of reported fatigue failed to support this premise; however, scores on the Diver Health Survey did exhibit a significant decrease following dives using EAN36 compared to air.

The results of the current study are consistent with the findings of previous research by Harris et al. (2003) who observed no discernable differences in fatigue levels following single, dry chamber, air and EAN36 dives. Harris et al. suggested the dive profile used in their study may not have induced the necessary decompression stress to distinguish between air and EAN36 post-dive fatigue. It was postulated that increased decompression stress might induce greater subjective fatigue ratings, possibly with significant differences between air and EAN36 dives. The open water, repetitive dive profile used in the current study was designed to accomplish this task. However, it may not have induced the necessary decompression stress to produce a statistically significant difference in fatigue levels. Charlton (1998) reported generally lower levels of fatigue and more energy among a group of research divers performing a series of repetitive, multiday dives using EAN. The benefits of EAN in reducing post-dive fatigue may only be realized over a series of dives carried out over multiple, continuous days. Further research is warranted to compare fatigue following a series of multiday, repetitive air and EAN dives.

The number of participants used in this study may have been too small to determine a trend or significant effect of breathing gas mixture on fatigue. With the fatigue levels and variability found in the current study, power analyses showed that over 100 participants would have been necessary to establish significance, a number which would be impractical for controlled, open water assessment using the current study's design.

Although the MFI-20 was used in previous research to assess acute, dive-related fatigue, the original intent of the tool was to measure fatigue in cancer patients. This tool may be inappropriate for measuring fatigue associated with SCUBA diving. The results did detect one expected outcome: divers were more fatigued after diving. The VAS results also suggested increased fatigue after diving. It was not apparent whether post-dive fatigue was induced through decompression stress or energy expenditure. It may be that the fatigue induced in the current study was primarily due to workload and thermoregulation. The question remains as to whether a smaller, more subtle difference in fatigue existed based on breathing gas mixture than could be detected by the MFI-20 or VAS.

The 90 min post-dive assessment may not have been the ideal time period for measuring fatigue. One measure of decompression stress experienced during a dive is the presence of venous gas emboli (VGE). It is known that VGE can circulate for hours upon conclusion of a dive (Dick et al., 1984; Radermacher et al., 1990). Although not a direct measure of post-dive fatigue, participants did respond with significantly higher DHS scores following air dives. This was in contrast to previous research that found no difference in DHS scores following EAN and air dives (Harris et al., 2003). This result supported the contention that multiple dives would induce a greater degree of decompression stress than a single exposure; however, it did not necessarily imply reduced fatigue following EAN36 dives. In response to question six of the Diver Health Survey, "How much of the time since your last dive have you felt full of energy?," 3 of 10 participants indicated less energy following test sessions using air. However, after his EAN test session, one participant remarked, "Although I didn't feel too fatigued within an hour of diving yesterday, by 3 pm I was feeling fatigued and wasn't feeling up to working on the computer." Future studies might consider multiple measurements beyond a 90 min period to compare changes in fatigue between air and EAN dives over a prolonged period. The difficulty would lie in controlling for other post-dive activities, such as caloric intake.

Three participants felt they would be able to determine which gas they were breathing during a test session. Only 1 of 3 guessed correctly. One commented that his breathing rate was better during one test session and, therefore, he assumed he was breathing EAN36. The data did not support this conjecture; the diver actually consumed 249.75 L (8.82 ft^3) more gas during the EAN test session. The diver perceived the same workload across test sessions, but reported a higher level of thermal comfort during the EAN test session.

Results from this study did not support the contention that using EAN36 as a breathing gas reduces post-dive fatigue. To date, research has indicated that there is no difference in fatigue levels between air and EAN36 dives. This conclusion has been supported by research using single, dry chamber and this study, which used repetitive, open water dive exposures. However, the conclusion from this study using a repetitive, open water dive protocol should be viewed with caution due to the low power of the design.

Development of a more suitable test tool for measuring acute changes in SCUBA-related fatigue may be warranted. Future research might consider studying individuals who report feeling less post-dive fatigue when using EAN to determine possible trends in dive profiles. A qualitative study exploring the feelings and common themes reported by divers affected by post-dive fatigue may be necessary. A comparison of venous gas emboli using Doppler ultrasound could provide more insight into the level of decompression stress exhibited following air and EAN dives. Fatigue induced through repeated hyperbaric exposure may be more chronic in nature and present itself over a prolonged period of time. Multiple assessments of post-dive fatigue, beyond the 90 min protocol used in the current study, could help determine if there is delayed onset. This may entail repeated measurements following repetitive dives or possibly assessing post-dive fatigue after repetitive, multiday profiles.

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