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MEASUREMENT OF FATIGUE FOLLOWING 18 msw OPEN WATER DIVES BREATHING AIR OR EAN36

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of the Requirements for the Degree
Master of Arts

by
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ABSTRACT

MEASUREMENT OF FATIGUE FOLLOWING 18 msw OPEN WATER DIVES BREATHING AIR OR EAN36

by Scott Damian Chapman

SCUBA divers often report feeling fatigued upon conclusion of diving activities. Postdive 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 postdive 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 postdive 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.

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Chapter I

Introduction

Self-contained underwater breathing apparatus (SCUBA) diving is an equipment-intensive activity requiring extensive training and an understanding of the inherent risks associated with breathing compressed gas in a hyperbaric environment. The dense water medium imposes higher energy requirements for movement, thermal regulation, and respiration. Fins are worn to aid in propulsion and thermal garments—wetsuits and drysuits—are used to protect against hypothermia. SCUBA regulators deliver gas at ambient pressure to allow for constant breathing rates at varying depths; however, a drawback of this mechanism is that a diver's body tissues must continually adjust gas levels toward equilibrium throughout the course of a dive. This leads to decompression stress both during and after a dive while metabolically inert gases are inspired and expired, respectively. Subsequent hyperbaric exposures (repetitive dives) occurring the same day and/or over a series of days (multiday) further compound physiological strain. It has been surmised that the increased energy demands and decompression stress accompanying a SCUBA dive may contribute to postdive fatigue, a general sense of tiredness or sleepiness often felt by divers after surfacing from a dive (Lang, 2001).

Fatigue is considered a risk factor for diving-related injuries (Marroni, 1994). It is plausible that the safety of repetitive dives may be compromised by the level of postdive fatigue accumulated during prior dives. In addition, higher levels of fatigue may affect data quality in experiments conducted by scientific divers. Determining a means for reducing fatigue after diving would benefit all divers and provide greater protection against fatigue-induced diving maladies.

Choosing and maintaining appropriate equipment for a particular environment is an important step in moderating the energy demands of a dive. Diving in the colder waters off the Central Coast of California requires thick wetsuits, possibly even dry suits, to stave off shivering thermogenesis and hypothermia. Modern SCUBA regulators provide compressed gas to divers at or slightly above ambient pressure, allowing for minimal breathing effort throughout the course of a dive. Proper diving technique contributes to overall energy efficiency underwater (Pendergast, Tedesco, Nawrocki, & Fisher, 1996). Experienced cold water divers generally have the appropriate equipment and skill level to manage a dive with minimal energy expenditure.

SCUBA divers plan a dive's depth, duration, ascent rate, and surface interval between dives in an effort to minimize decompression stress experienced during the uptake and elimination of inert gas, primarily nitrogen. If a diver were to ascend too quickly relative to the depth and duration of a dive, potentially harmful bubbles of inert gas could form in body tissues and/or blood vessels, disrupting oxygen delivery. This dangerous condition, termed decompression sickness (DCS), requires immediate medical attention and likely treatment in a hyperbaric chamber.

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 postdive fatigue (Charlton, 1998; Lang, 2001). The mechanism by which this may occur is not clearly understood; however, it has been purported that postdive 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 postdive fatigue. The only known study to test this premise found no significant difference between fatigue levels following air and EAN dives (Harris, Doolette, Wilkinson, & Williams, 2003). Despite the results of the Harris et al. study, at least one SCUBA training agency still promotes this purported benefit of EAN (IANTD Faq's, n.d.).

Harris et al. (2003) conducted a double-blind study of simulated dives to 18 m of sea water (msw) in a dry hyperbaric chamber. Eleven certified divers, ages 35-45, participated in their study and performed a total of two, 40 min dives—one breathing air, the other breathing EAN36—on separate, nonconsecutive days. Fatigue levels were assessed immediately before and after each dive using multiple test tools. No statistically significant differences were found between breathing gases in relative postdive fatigue level (Harris et al., 2003). Harris et al. acknowledged that the single, dry chamber dive profile may not have induced enough decompression stress to observe a difference between air and EAN36 postdive 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, Corleo, Balestra, Voellm, & Pieri, 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 postdive fatigue, assessment following repetitive dives in an open water environment may provide the combined stimuli to produce a significant difference between air and EAN postdive fatigue.

The purpose of this study was to compare pre- and postdive fatigue levels reported by participants following repetitive SCUBA dives in an open water environment. 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 postdive fatigue levels following air and EAN dives.

Eleven certified male SCUBA divers, ages 18-35, were asked to participate in two test sessions separated by a minimum of 48 hr. 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 a drysuit). The minimum 12 dive requirement was consistent with active diving standards established in scientific diving manuals (American Academy of Underwater Sciences [AAUS], 2005). 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, St. Leger Dowse, Edge, Gunby, & Bryson, 2003). Participants were required to use the same gear configuration, including thermal protection, during all dives to maintain consistency between test sessions. Circadian rhythm fluctuations were controlled by testing individuals at approximately the same time of day for both test sessions.

Participants were informed that they would be performing two test sessions, each consisting of two, 30 min dives at 18 msw separated by a 1 hr surface interval. Air was used as the breathing gas in both dives within one test session while EAN36 was used in the other, in random order. The 1 hr surface interval allowed for adequate elimination of accumulated nitrogen between dives to reduce the risk of decompression sickness to a level accepted within recreational dive limits. Both researcher and participant were blind to gas mixture being utilized during all test sessions, similar to methods employed by

Harris et al. (2003). The oxygen fraction of 0.36 was selected to provide the largest differential between oxygen concentrations of common EAN mixes and air. Each dive required swimming laps along a 20 m transect at a speed of 18.29 m/min to maintain consistency in energy output per test session. Dujić et al. (2005) used a similar rate of 17 m/min to assess the effects of low intensity (approximate oxygen consumption rate of 13 $ml \cdot kg^{-1} \cdot min^{-1}$) underwater exercise on decompression stress in fit divers. Swimming laps helped minimize any effects of current and surge.

Fatigue was assessed before each test session and 90 min after the second dive of each test session 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 5 subscales measuring different aspects of fatigue. It is a validated tool that has been used to evaluate fatigue after SCUBA diving and physical activity (Harris et al., 2003; Smets, Garssen, Bonke, & De Haes, 1995). 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 postdive fatigue levels (Grant et al., 1999; Harris et al., 2003).

Inert gas bubbles have been detected in venous circulation postdive and may not be completely eliminated for several hours (Marroni et al., 2000; Radermacher et al., 1990). The 90 min postdive interval for fatigue assessment was implemented in an effort to account for continued decompression stress beyond the duration of the actual dive.

Twenty-four hours after the second dive, participants completed the Diver Health Survey (DHS). This tool has been validated for assessing general symptoms indicative of decompression illness (Doolette, 2000). A test session was considered complete once all posttests were completed.

Statement of the Problem

Fatigue is a contributing factor to decompression sickness (Marroni, 1994). Divers often report feeling fatigued following a SCUBA dive, while anecdotal reporting continues to suggest that using EAN reduces postdive fatigue. Determining a means for minimizing postdive fatigue would effectively lower the risk of DCS in repetitive dive profiles. In addition, training course advertisements state that EAN reduces postdive fatigue (IANTD, n.d.); the dive community would benefit from knowing whether this purported claim is true.

Statement of Purpose

The purpose of this study was to compare subjective fatigue levels in SCUBA divers between two test sessions consisting of two repetitive dives breathing either air or EAN36 in an open water environment.

Research Hypothesis

The lowered fraction of nitrogen and corresponding increase in oxygen fraction will lead to a reduced level of fatigue reported by divers breathing EAN36.

Delimitations

- Participants consisted of men between the ages of 18-35 years.
- Square-dive profiles in a cold water environment (10-15 °C) were utilized.

- Each test session consisted of only two 18 msw repetitive dives.
- Only EAN mixtures containing 36% oxygen were used.
- All divers had SCUBA leadership or scientific diving experience.

Limitations

- Participants experienced variations in current, swell, visibility, water temperature, and air temperature.
- Participants may not have been able to accurately assess fatigue consistently between test sessions.
- Predive fatigue may have been affected if participants failed to follow pretest instructions.
- Fatigue was measured 90 min after the second dive; this may not be the optimal time to measure fatigue.
- Divers provided their own thermal equipment which may or may not have been adequate for conditions in Monterey Bay.

Definitions

Atmospheric pressure absolute (ata): absolute pressure in atmospheres; in SCUBA diving it relates to the sum of atmospheric pressure and hydrostatic pressure.

Barotrauma: injury resulting from inadequate equalization between pressure in body cavities (e.g., ears, lungs, sinuses) and surrounding water pressure.

Decompression stress: physiological strain while the body attempts to maintain homeostasis during a reduction in ambient pressure.

Enriched-air nitrox: a breathing gas mixture containing greater than 20.93% oxygen; it is often created by mixing 100% oxygen with air.

Fatigue: "complaints of being tired, experiencing a lack of sleep or a generalized tiredness" (Diving Medical Dictionary, n.d., F section).

Multiday: a set of dives taking place on more than one day, separated by a maximum of 24 hr.

No-decompression stop limit: amount of time available at depth that allows a direct ascent to the surface without a mandatory decompression stop.

Repetitive dive: any dive occurring between 10 min and 12 hr after a previous dive.

Summary

SCUBA divers report a reduction in postdive fatigue when using EAN as a breathing gas. To date, only one other study has analyzed whether or not differences in subjective fatigue levels are discernable when comparing air and EAN dives. The results yielded no statistically significant differences. The previous study assessed single dive exposures in a dry, hyperbaric chamber. In contrast, the current study increased decompression stress by having divers perform repetitive dives in an open water environment. It was expected that the increased demands of the dive profile would elicit greater overall differences in subjective fatigue levels.

Chapter II

Review of Literature

This section provides detailed information related to postdive fatigue, enriched-air nitrox, hyperoxia, and tools to measure fatigue. An overview of diving physics and physiology is also included as background information for ensuing topics.

Diving Physics and Physiology

Understanding the effects of breathing in a hyperbaric environment requires knowledge of the physical laws governing the behavior of gases, particularly Boyle's law, Dalton's law, and Henry's law. The effects of these laws impact dive safety, creating the potential for several diving maladies including pulmonary barotrauma and decompression sickness.

Unlike liquids and solids, gases are highly compressible and evenly disperse to completely occupy their enclosure. Boyle's law states that at a constant temperature, there is an inverse relationship between gas volume and pressure (Taylor, 2004). At sea level, the atmosphere exerts 1 atm (10 N/cm^2) of pressure (Armstrong, 2000). Underwater, ambient pressure is directly related to depth, increasing 1 atm for every 10 msw (Taylor). The varying pressure has a direct impact on gas-filled spaces within a diver's body. Avoiding barotrauma is a primary concern; SCUBA divers must maintain pressure equilibrium at all times within affected areas (e.g., ears, sinuses, and lungs).

At depths greater than 1 m, humans become incapable of breathing normobaric gases as respiratory muscles are unable to overcome the difference between internal and external pressure (Sanford, 1974). SCUBA compensates for this limiting factor by delivering compressed gas at ambient pressure. The increased gas density maintains lung volume near normobaric levels, enabling respiration at varying depths (Armstrong, 2000). However, if SCUBA divers hold their breath during a concurrent drop in ambient pressure (e.g., while ascending), pulmonary barotrauma may occur. In some cases, gas emboli enter arterial vasculature and eventually block cerebral pathways (U.S. Navy, 2005). Divers succumbing to arterial gas embolism rapidly exhibit a number of symptoms including unconsciousness, paralysis, numbness, weakness, vertigo, and bloody sputum (U.S. Navy).

Dalton's and Henry's laws describe the relationship of partial pressures and gas solubility, and relate to indirect pressure effects experienced by SCUBA divers. Gases are often a mixture of multiple molecules, all of which contribute to the total pressure exerted by the gas. Dalton's law describes this relationship, stating that the total pressure of a gas is the sum total of the partial pressures of the component gases (Taylor, 2004). For example, air is primarily comprised of oxygen and nitrogen; oxygen molecules contribute 20.93% of air pressure, nitrogen 78.08%; other gases account for the remainder. Henry's law describes the solubility of a gas relative to its partial pressure at a given temperature: the concentration of a gas in solution is directly proportional to the partial pressure of the gas above the solution (Taylor).

While descending, increasing gas density in a diver's lungs leads to an influx of higher concentrations of nitrogen and other constituent gases from a diver's breathing supply (absorption or ongassing). During ascent, gases start to flow out of the body (elimination or offgassing). The balance between absorption and elimination is controlled by dive time, depth, and ascent rates. The gas gradient at the tissue-blood interface drives the gas exchange, the overall transfer process being a combination of blood perfusion and gas diffusion rates, dependent on local blood flow rates and vascularity (Wienke, 2001).

If an ascent is too fast relative to dive depth and duration parameters, divers are at risk of developing DCS: "a syndrome caused by bubbles of inert gas forming in the tissues and bloodstream during or after ascent from a dive" (Diving Medical Dictionary, n.d., D section). Using air as a breathing medium, the bubbles, or emboli, consist of nitrogen, since oxygen is used metabolically. Depending on where emboli emerge, disruptions in vascular flow, tissue damage, and localized hypoxia may follow (U.S. Navy, 2005). Signs and symptoms include pain, numbness or paresthesia, headache, dizziness, nausea, paralysis, and unconsciousness (Sanford, 1974). Decompression sickness is a serious condition that most often requires treatment in a hyperbaric chamber to shrink emboli and allow for gas diffusion. There may be differences in susceptibility to decompression sickness between male and females. Lee et al. (2003) found that women had a higher incidence of DCS during the first week of the menstrual cycle. Studies involving the measurement of decompression stress need to account for potential gender-related variation.

The behavior of gases under varying pressures is responsible for the limiting depth and time restrictions placed upon recreational SCUBA divers. The two primary gases comprising air, oxygen and nitrogen, can have deleterious effects on SCUBA divers at increased partial pressures. Nitrogen has a narcotic effect on SCUBA divers as they descend into deeper waters. This effect, termed nitrogen narcosis, may impair decision making processes and endanger the safety of a diver. Susceptibility to nitrogen narcosis varies, but most individuals will feel its effect beyond 40 msw (Strauss & Aksenov, 2004). High partial pressures of oxygen also pose a threat to the safety of a diver. Disruptions to cellular metabolism resulting from excessive exposure to higher partial pressures of oxygen may lead to pulmonary and central nervous system complications (Strauss & Aksenov). Based on the depth/duration profile of a planned dive, relative levels of oxygen and nitrogen in a breathing gas mixture may be manipulated to provide the greatest degree of safety.

It is imperative that individuals are in good health and do not have any conditions that could potentially inhibit gas diffusion and perfusion throughout a dive. Furthermore, SCUBA divers must undergo extensive training to ensure they are informed of the potential risks associated with visiting a hyperbaric environment.

Postdive Fatigue

A general sense of tiredness or sleepiness after diving, termed postdive fatigue, has been reported upon conclusion of SCUBA dives (Lang, 2001). The cause of postdive fatigue has been anecdotally attributed to increased energy demands required in a hyperbaric environment and/or a physiological reaction to decompression stress (Lang). Fatigue is considered a risk factor for developing DCS (Marroni, 1994). Reducing postdive fatigue levels could benefit SCUBA divers by lowering the risk of developing DCS during subsequent repetitive and multiday dive profiles.

SCUBA diving involves entering an environment that is often cold, requires physical stamina, and subjects divers to varying pressures. Thermoregulatory demands, breathing resistance, and effort required for propulsion through a denser medium result in increased energy expenditure in a hyperbaric environment when compared to normobaric conditions (Doubt, 1996; Pendergast et al., 1996). Body heat dissipates up to four times faster in water than in air of the same temperature (Armstrong, 2000). Without proper thermal insulation, SCUBA divers may develop hypothermia. As a diver's body temperature drops, shivering thermogenesis and heat production from movement and energy metabolism are employed in an effort to maintain heat balance (Armstrong). Strong currents can amplify energy costs of a dive. Bove (1996) indicated that swimming against a 1.3 knot (2.41 kph) current with diving gear requires 13 METS, or an approximate oxygen consumption of 45 $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. Due to these increased energy demands of SCUBA diving, it is not surprising individuals often feel fatigued after diving. Compounding the energy cost, repetitive dives may add additional stress on a diver's body and potentially lead to greater postdive fatigue.

Underwater swimming profile and gear configuration also play a significant role in relative energy cost per diver (Pendergast et al., 1996). Energy cost is minimized when divers swim in a horizontal position, streamline gear, and optimize kicking depth and frequency to reduce drag, but maintain efficiency. Experienced divers tend to have lower energy expenditure due to better technique and swimming posture (Pendergast et al.). To eliminate unnecessary energy expenditure due to poor diving skill, it is important that experienced divers serve as participants when assessing postdive fatigue. Veteran divers would be more likely to maintain a consistent profile during multiple dive outings without showing marked changes in skill level.

SCUBA divers absorb and eliminate inert breathing gases throughout the course of a dive and upon surfacing (Dick, Vann, Mebane, & Feezor, 1984; Radermacher et al., 1990). During elimination phases, the body undergoes decompression stress as it attempts to achieve homeostasis. Venous gas emboli (VGE) have been found to be a common occurrence following hyperbaric exposures that remain within no-decompression stop limits and exhibit no overt DCS complications (Carturan et al., 2002; Marroni et al., 2000). Marroni et al. evaluated postdive Doppler recordings from a combination of 521 single and repetitive dives collected in the Diver's Alert Network Europe SAFE DIVE project from 1995 to 1999. VGE monitoring was performed every 10 to 15 min for 75 to 90 min postdive. In total, 55% of these dives were bubble free, 22% were considered to have low bubble counts, while the remaining 23% had high bubble counts. However, when the authors isolated repetitive dive data, only 15% were bubble free, 18% had low bubble counts, and 67% had high bubble counts. These data imply that an increased decompression stress is present during subsequent dives.

The propensity of repetitive dives to induce VGE is not surprising considering that nitrogen desaturation continues for several hours postdecompression (Dick et al., 1984; Radermacher et al., 1990). Increased baseline nitrogen levels at the beginning of a repetitive dive would seemingly lead to increased decompression stress during ascent and a higher likelihood of subsequent bubble formation. The increased postdive nitrogen levels accompanying decompression stress may also be related to postdive fatigue. Dick et al. measured nitrogen elimination rates and found postdive fatigue to be associated with slow rates of nitrogen desaturation.

In summary, SCUBA diving involves increased energy demands due to environmental conditions, technique, and gear configurations. Divers undergo decompression stress while eliminating inert gases during ascent and for a period of time after the conclusion of a dive. It is common for inert gas to form into VGE, particularly following repetitive dives. Both increased energy expenditure and decompression stress have been suggested as having a causal relationship with postdive fatigue.

Enriched-Air Nitrox

Enriched-air nitrox is a breathing gas mixture used in SCUBA diving that has a greater concentration of oxygen than found in air (> 20.93%). SCUBA divers use EAN to reduce nitrogen absorption during a dive. The benefits of EAN include less susceptibility to decompression sickness compared to air dives of similar depth/duration, and longer dive times compared to air dives of similar depth. However, using EAN limits maximum safe diving depth due to a greater potential for oxygen toxicity. The two most common mixes used in recreational diving are EAN32 and EAN36 which have 32% and 36% oxygen, respectively (Diving Medical Dictionary, n.d.).

Anecdotal reports suggest that using EAN reduces postdive fatigue (Charlton, 1998; Lang, 2001). The combination of reduced nitrogen and increased oxygen levels are purported to stave off complications associated with decompression stress. Research in this area is very limited with only one known empirical study. Harris et al. (2003) conducted a double-blind study assessing 11 certified SCUBA divers for fatigue, attention, and concentration levels immediately before and after dry hyperbaric chamber dives to 18 msw breathing either air or EAN36. Their participants performed two, 5 min bouts of low intensity exercise (5 METS or an approximate oxygen consumption of 17 $ml \cdot kg^{-1} \cdot min^{-1}$) during the protocol to simulate the workload of a recreational SCUBA dive. Temperature was maintained between 22-24 °C. They found no significant differences in any measures of fatigue; improvements in concentration levels were attributed to a learning effect of the test protocol.

The question remains whether simulated dry chamber dives are representative of fatigue levels experienced following actual underwater dives. SCUBA diving often requires constant movement and continual thermoregulation, potentially increasing the energy demands throughout the course of a dive. Short bouts of exercise in a dry, thermoneutral environment may not induce the same energy demands as an open water dive of similar depth and duration. Additionally, the single dive exposure used in the Harris et al. (2003) study may not have subjected divers to a high degree of decompression stress. Marroni et al. (2000) determined that single dive profiles tend to produce less VGE than repetitive dives. It has also been reported that simulated dives in a hyperbaric chamber produce less bubble formation than similar dive profiles in open water settings (Gardette, Chuitton, Sciarli, & Fructus, as cited in Carturan et al., 2002). Perhaps, multiple, same-day dives conducted in open water would increase energy demands and decompression stress sufficiently to induce a significant difference in subjective fatigue ratings between air and EAN dives. Further research is warranted to determine whether repetitive dives in an open water environment would produce similar results to the findings of Harris et al. (2003).

Hyperoxia

In normobaric environments, hyperoxic breathing supplies, having a partial pressure of oxygen greater than 0.21 atm, can be created by mixing 100% oxygen with air. EAN is an example. Hyperoxic breathing mediums are also present in pressurized environments (e.g., hyperbaric chambers) due to increased gas densities relative to ambient pressure. Hyperoxia has been shown to increase aerobic exercise performance (Pardy & Bye, 1985; Perry, Reid, Perry, & Wilson, 2005; Wilson & Welch, 1975) and reduce subjective fatigue ratings (Sung, Min, Kim, & Kim, 2005).

Wilson and Welch (1975) measured time to exhaustion for nine male participants running on a treadmill as they breathed air, 40%, 60%, 80%, or 100% oxygen. They determined all hyperoxic gas mixtures led to an increase in the mean time to exhaustion with the greatest improvement, 38%, achieved when utilizing 100% oxygen. Pardy and Bye (1985) found similar results while comparing diaphragmatic fatigue in individuals breathing air or 100% oxygen against a variable resistance. Mean time to fatigue was nearly doubled for participants breathing 100% oxygen. Perry et al. (2005) found power output could be increased 8.1% during hyperoxic training, with the results sustainable over a prolonged (6 week) training program. It has also been shown that under resting conditions, hyperoxic gas mixtures reduce subjective ratings of fatigue. Sung et al. (2005) measured perception of fatigue of healthy college students breathing 0.18, 0.21, and 0.30 fractions of oxygen while driving. Mental fatigue was markedly decreased in the high oxygen test cases, with participants displaying improved reaction times and reduced tiredness. The results from these studies would seemingly apply to a hyperbaric environment where individuals breathe relatively higher partial pressures of oxygen compared to sea level. For example, the partial pressures of oxygen in compressed air and EAN32 at 15 msw are 0.52 ata and 0.80 ata, respectively. This is theoretically equivalent to breathing 52% and 80% oxygen mixes at the surface. It has been determined that higher percentages of oxygen increase time to fatigue (Pardy & Bye; Wilson & Welch, 1975). Perhaps the increased fraction of oxygen in EAN36 would reduce energy expenditure during a dive, resulting in decreased ratings of postdive fatigue.

While it is known that nitrogen is a metabolic depressant under hyperbaric conditions, it has been suggested that it may also have a depressant effect at normobaric partial pressures (Jordan, Simmons, Lassiter, Deshpande, & Diershke, as cited in Wilson & Welch, 1980). Wilson and Welch (1975) hypothesized that performance improvements during hyperoxic exercise may be due to the reduced fraction of nitrogen, rather than the higher percentage of oxygen. However, while comparing exercise performance breathing various combinations of O_2-He to O_2-N_2, this premise was not fully supported (Wilson & Welch, 1980). Wilson and Welch (1980) did find higher performance levels with the absence of nitrogen, but felt the gains were more likely due to the reduced cost of breathing associated with helium mixtures rather than the removal of a metabolic depressant.

Hyperoxic breathing mixtures are also recommended and utilized for SCUBA first aid and treatment. Divers afflicted with DCS or arterial gas embolism, collectively termed decompression illness due to their similar treatment protocols, are administered the highest concentration of oxygen available in an effort to facilitate inert gas removal, oxygenate blood plasma, and reduce the size of emboli. From this perspective, hyperoxia is reducing or combating the effects of excessive decompression stress.

In summary, hyperoxia does increase exercise performance during aerobic activities. The response may be due to the increased fraction of oxygen or a lower fraction of nitrogen. EAN increases oxygen concentration relative to air and may reduce energy requirements during a dive, potentially decreasing postdive fatigue.

Measuring Postdive Fatigue

Fatigue is a subjective symptom, making its measurement and generalization somewhat difficult. Physiologically, it may be defined in terms of energy depletion; psychologically, it may be defined in terms of motivational factors (Aaronson et al., 1999). The Diver's Alert Network (DAN), a nonprofit agency dedicated to diver safety and health, defines fatigue in terms of both tiredness and sleepiness (Diving Medical Dictionary, n.d., F section). The definition provided by DAN encompasses the generalized feeling of postdive fatigue often reported upon conclusion of SCUBA dives and was used as the definition of fatigue in this study. Analyzing levels of pre- and postdive fatigue requires testing tools capable of capturing acute changes over relatively short time periods—for this study, approximately 4 hr between measurements.

The Multidimensional Fatigue Inventory (MFI-20) is a 20 item questionnaire that measures five dimensions of fatigue: general fatigue, physical fatigue, mental fatigue, reduced motivation, and reduced activity (Smets et al., 1995). The tool has been validated to detect differences between groups, within groups, and between conditions, with the subscale of general fatigue showing the greatest sensitivity to acute change. Individuals indicate, on a 5-point Likert scale, the degree to which each question applies to their current state of being. According to Harris et al. (2003), a 5 point difference in fatigue levels is considered significant for each subscale. In comparing pre- and postdive fatigue levels, Harris et al. used the MFI-20, scoring only the general, physical, and mental fatigue scales. No explanation was provided for their decision; however, Smets et al. did report low internal consistency scores for reduced motivation and reduced activity when assessing fatigue levels induced through physical effort. Harris et al. were the first to use the MFI-20 to measure acute changes over a short duration and indicated the tool may not have been sensitive to differences in fatigue levels over their single dive protocol. Introducing a repetitive dive protocol should induce greater energy expenditure and decompression stress, thereby potentially increasing the discrepancy between pre- and postdive fatigue.

The original directions of the MFI-20 ask participants to interpret questions in terms of how they have been feeling lately. In an effort to direct the tool toward measuring acute change in this study, the directions were modified, asking participants to answer in terms of how they feel “right now.” In addition, general fatigue, physical fatigue, and mental fatigue subscales provide a higher consistency rating for physical activity. For this reason, only these subscales were scored to assess pre- and postdive fatigue levels.

A Visual Analogue Scale (VAS) is a measurement tool used to evaluate data occurring along a continuum. It consists of a horizontal line, commonly 100 mm in length, with word descriptors on each end, representing the extremes of the data range. A specific question is asked with respect to what is being measured. As an example, in measuring fatigue, the question: "How fatigued are you feeling right now?" might be anchored by "no fatigue" and "very fatigued." The VAS has been shown to have a high degree of reproducibility in measuring general fatigue during submaximal exercise (Grant et al., 1999) and has been used to measure ratings of subjective fatigue induced through SCUBA dives and daily activity (Harris et al., 2003; Ip et al., 2006).

Convergent validity of the MFI-20 was determined by comparing results to VAS-fatigue scores (Smets et al., 1995). The subscales of general and physical fatigue showed strong correlations (0.77 and 0.70, respectively, $p < 0.001$). In assessing pre- and postdive fatigue levels using these tools, strong agreement between results is expected.

In summary, the MFI-20 and VAS are both validated tools that have been used to assess fatigue levels related to physical exertion. The tools should provide a reasonably accurate measure of acute changes in pre- and postdive fatigue levels.

Summary

Postdive fatigue has been self-reported at the end of SCUBA dives and may result from increased energy expenditure, decompression stress, or a combination of the two. It has been suggested that using EAN reduces the level of postdive fatigue. This may be due to the reduced fraction of nitrogen breathed throughout a dive, leading to a decrease in decompression stress. Hyperoxic breathing mixtures have also been shown to increase aerobic exercise performance and decrease subjective fatigue levels.

Chapter III

Methods

This section describes the procedures used to implement this study. Participants, instrumentation, procedures, and statistical analysis are discussed.

Participants

Participants consisted of 11 healthy male volunteers between the ages of 18-35 years who were certified, active SCUBA divers. Participants were EAN and Rescue Diver certified. Eight participants were certified AAUS divers with documented, full physical examinations for diving performed within the past year. The remaining three participants held SCUBA leadership certifications and were asked to complete the Recreational SCUBA Training Council medical questionnaire (Appendix A) to assess current fitness for diving.

Instrumentation

Assessment tools. Fatigue was assessed using the Multidimensional Fatigue Inventory (Appendix B) and a 100 mm Visual Analogue Scale (Appendix C). The Diver Health Survey (Appendix D) was administered for postdive assessment of potential decompression illness symptoms. Perceived workload and thermal comfort were measured after each dive using a subset of questions from the Diver's Alert Network Project Dive Exploration questionnaire (Appendix E).

SCUBA equipment. 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.

Dive planning tools. 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 (Appendix F).

Procedures

The methods employed in this study were approved by the Institutional Review Board in accord with the ethical principles for research involving human subjects at San Jose State University (Appendix G). Participants were informed that they were being asked to participate in an underwater research project assessing postdive 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 to participate in the study (Appendix H). In the unlikely event of a diving accident, a certified Diving Medical Technician was available for consult during all test sessions.

Dive protocol. Participants were required to participate in two test sessions separated by a minimum of 48 hr. 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 hr prior to testing (Appendix I).

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 (Appendix J).

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. Both participant and researcher were unaware of which test session utilized EAN36. Decompression and oxygen loading parameters were analyzed for both breathing mixtures to assure participants of safe dive profiles that fell within recommended no-decompression stop limits. Underwater signals and safety protocols were discussed in detail. Participants were offered water, granola bars, bagels, yogurt, and bananas at each test session. They were not required to consume these items, but were asked to be consistent in snack choice between test sessions.

A test session dive plan consisted of two, 30 min square profile dives at a depth of 18 msw, separated by a 1 hr surface interval (Appendix K). Participants dove in teams of two, maintaining close proximity (within 1 m of each other). Either participant could have aborted 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. If this had occurred, the test session would have been terminated and rescheduled.

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/min. Participants were to begin an ascent at a rate of 9 m/min when their total bottom time reached 25 min. If a problem occurred or a dive team member's SPG read 700 psi (49.22 kg/cm^2) or below, 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/min. 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. 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. A test session concluded with participants completing the DHS 24 hr after the second dive.

Cylinder filling and logging protocol. 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 course of the study (Appendix L). 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 Analysis

The independent variable used in this study was breathing gas (air or EAN36). The dependent variables were fatigue, workload, and thermal comfort. The general fatigue, physical fatigue, and mental fatigue 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 postdive 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 determine correlation coefficients 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.).

Chapter IV

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 (°C)	Depth (m)	Time Underwater (min)	Time Swimming (min)	Speed (m/min)	Distance Swam (m)	Gas Used (L)
M	11.97	17.28	30.23	21.05	17.21	362.47	1626.68
SEM	0.19	0.09	0.25	0.26	0.23	6.99	30.87

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 ± 0.41 m/min and 6.7 ± 0.18 m/min (*M* ± *SEM*), respectively. These were slightly slower than the prescribed rates.

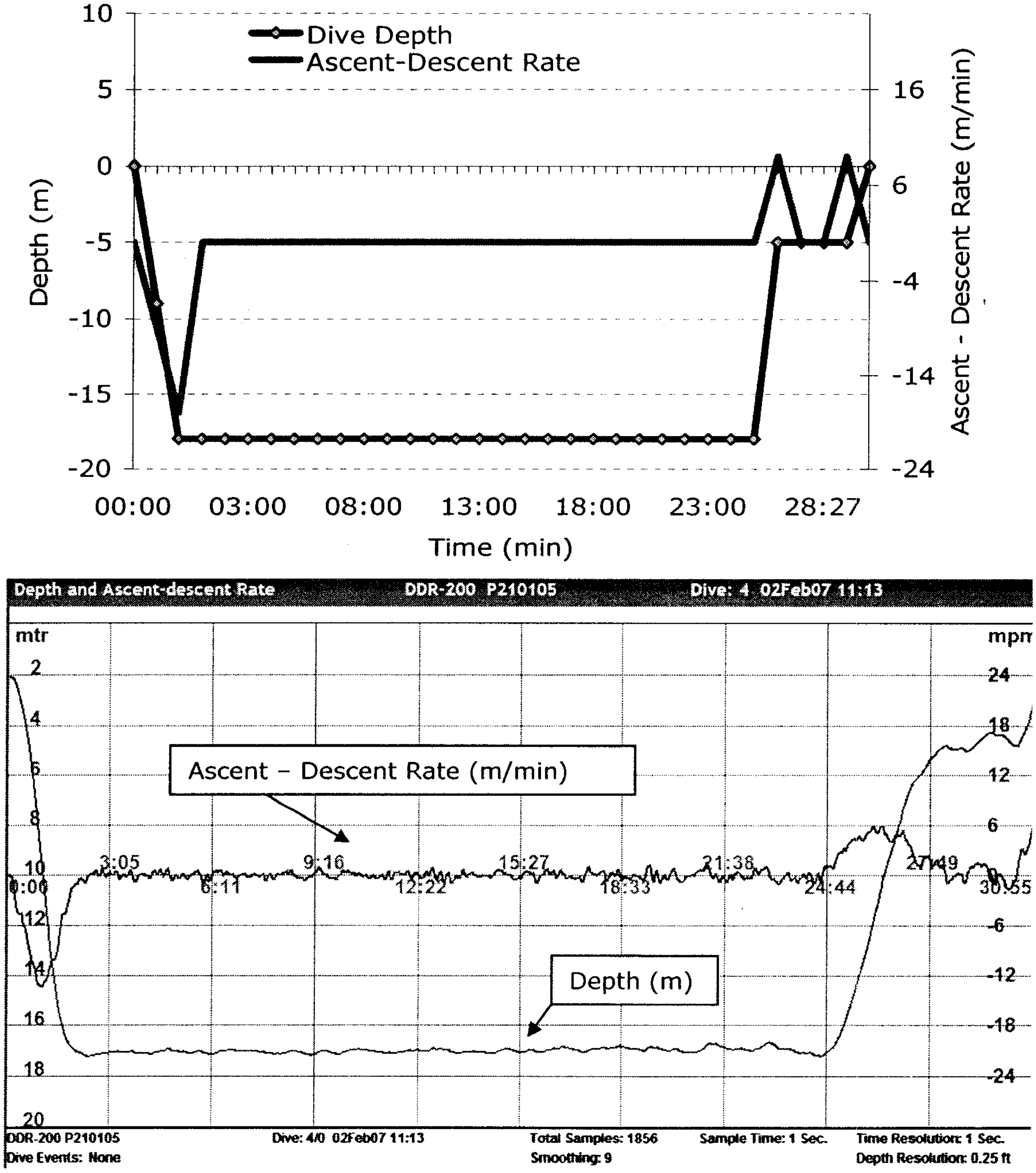

Figure 1. Planned profile (top) and actual data retrieved from the Cochran DDR-200 (bottom).

Fatigue Analyses

Analyses of the VAS and the mental fatigue (MF), general fatigue (GF), and physical fatigue (PF) subscales of the MFI-20 were performed. Two-way repeated measures ANOVA was used to examine the effect of breathing gas mixture (air and EAN36) on fatigue, differences between pre- and postdive fatigue ratings, and the interaction between gas mixture and pre- and postdive fatigue ratings.

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, postdive fatigue levels, 39.2 ± 4.3 mm, tended to be greater than predive ratings, 26.4 ± 3.6 mm ($M \pm SEM$), 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 postdive fatigue ratings.

MFI-20. There were no statistically significant differences between breathing air or EAN36 on fatigue ratings. There were statistically significant differences in postdive fatigue compared to predive 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 postdive fatigue ratings (see Figure 2). There were no significant interactions between breathing gas mixture and pre- and postdive fatigue ratings. ANOVA data are summarized in Table 2.

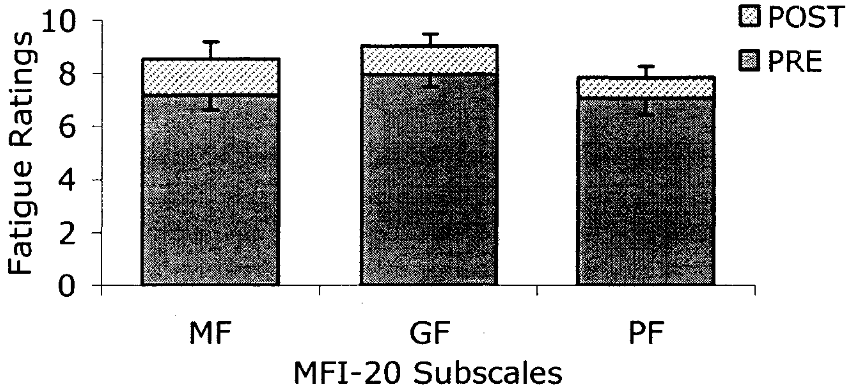

Figure 2. Least squares mean fatigue responses for mental fatigue (MF), general fatigue (GF), and physical fatigue (PF) subscales of the MFI-20 pre- and postdive, independent of breathing gas mixture.

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	0.0909	0.0909	0.0121	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).

Postdive Health Analysis

Diver Health Survey responses were evaluated after each test session to determine if participants were experiencing signs and 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 posttest 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 ($M \pm SEM$), 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

This section discusses the relationships between amount of breathing gas consumed, thermal comfort, workload, temperature, and swimming speed. Thermal comfort was rated on a scale of 1 (cold) to 5 (warm), and workload was rated 1 (light) to 5 (hard). Table 2 shows the Pearson product-moment correlation coefficients between these variables. Small, positive correlations were found between gas consumed and workload ($r = 0.32$, $p = 0.0344$) and thermal comfort and temperature ($r = 0.404$, $p = 0.00652$). 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 $p = 0.0344$	-0.0874 $p = 0.573$	0.174 $p = 0.259$
Thermal Comfort		0.0765 $p = 0.622$	0.404 $p = .00652$	-0.0731 $p = 0.673$
Workload			-0.118 $p = 0.447$	0.185 $p = 0.229$
Temperature				-0.0292 $p = 0.851$

Note. Gas consumed was measured in psi, temperature in °C, 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).

Summary

Results from the subjective fatigue tests showed that divers were more 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.

Chapter V

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 postdive 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 postdive 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 postdive 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 postdive 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. It is known that VGE can circulate for hours upon conclusion of a dive (Dick et al., 1984; Radermacher et al., 1990). Marroni et al. (2000)

found high levels of VGE 90 min after repetitive dives. Although not a direct measure of postdive fatigue, participants did respond with significantly higher, accumulated 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 postdive 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 postdive 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 repetitive, open water dive exposures. However, the conclusion from the repetitive, open water dive protocol should be viewed with caution due to the low power of the study 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 postdive 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 postdive 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 postdive 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 postdive fatigue after repetitive, multiday profiles.

Summary

To determine the effect of breathing gas mixture, this study compared subjective fatigue ratings before and after repetitive dives using air and EAN36. The results were consistent with past research; there were no differences in fatigue levels relative to percentage of oxygen in the breathing gas. Participants did exhibit greater fatigue after diving, but the underlying mechanism leading to the increased fatigue was not determined. Future research might consider measuring venous gas emboli using Doppler ultrasound, performing multiple assessments of fatigue following repetitive and multiday dive profiles, and implementing a qualitative design to determine common themes reported by those exhibiting postdive fatigue.

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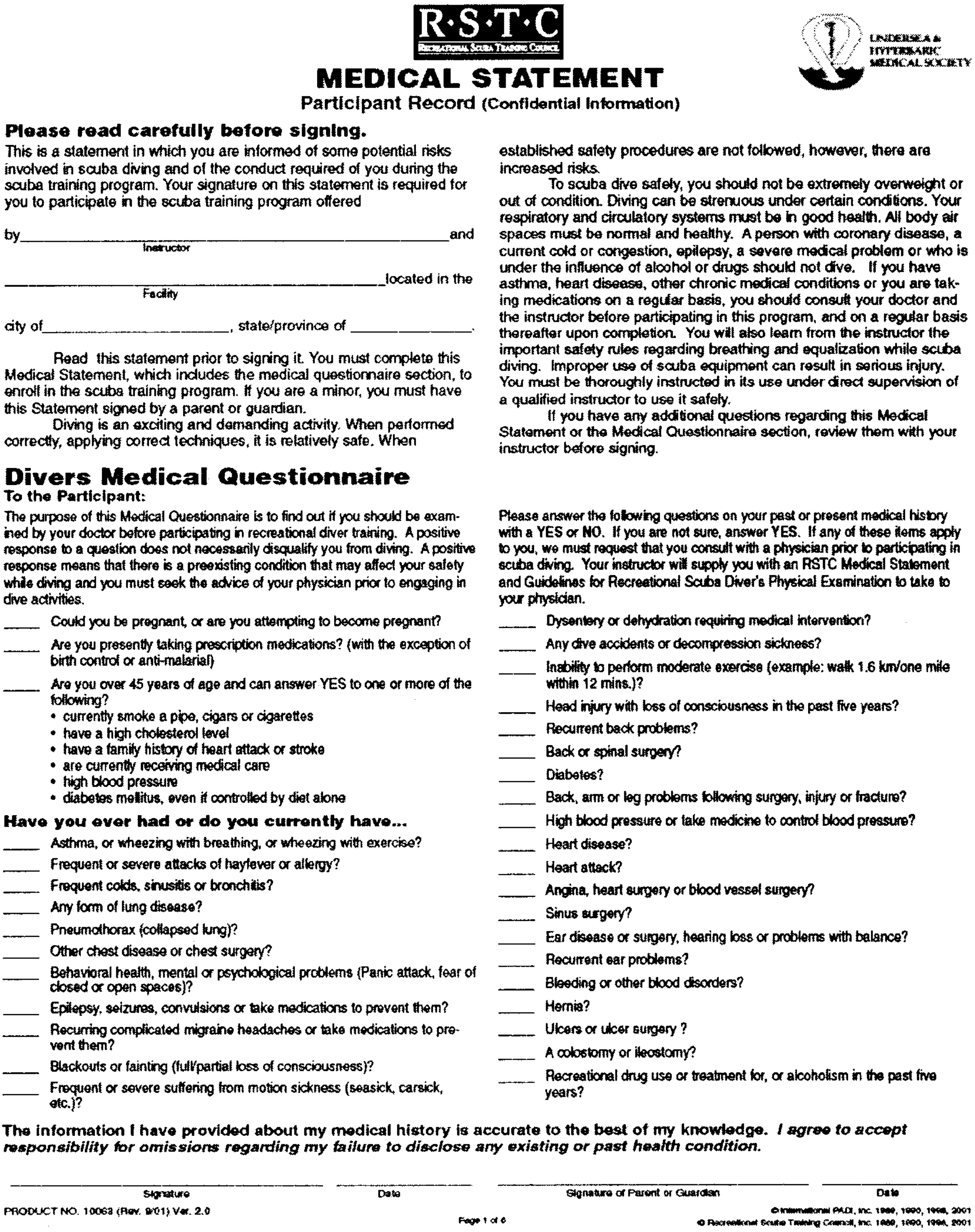
Appendix A

Divers Medical Questionnaire



R·S·T·C

UNDERSEA & HYPERBARIC MEDICAL SOCIETY

MEDICAL STATEMENT

Participant Record (Confidential Information)

Please read carefully before signing.

This is a statement in which you are informed of some potential risks involved in scuba diving and of the conduct required of you during the scuba training program. Your signature on this statement is required for you to participate in the scuba training program offered

by______________________________________and
Instructor

______________________________________located in the
Facility

city of__________________, state/province of _____________.

Read this statement prior to signing it. You must complete this Medical Statement, which includes the medical questionnaire section, to enroll in the scuba training program. If you are a minor, you must have this Statement signed by a parent or guardian.

Diving is an exciting and demanding activity. When performed correctly, applying correct techniques, it is relatively safe. When established safety procedures are not followed, however, there are increased risks.

To scuba dive safely, you should not be extremely overweight or out of condition. Diving can be strenuous under certain conditions. Your respiratory and circulatory systems must be in good health. All body air spaces must be normal and healthy. A person with coronary disease, a current cold or congestion, epilepsy, a severe medical problem or who is under the influence of alcohol or drugs should not dive. If you have asthma, heart disease, other chronic medical conditions or you are taking medications on a regular basis, you should consult your doctor and the instructor before participating in this program, and on a regular basis thereafter upon completion. You will also learn from the instructor the important safety rules regarding breathing and equalization while scuba diving. Improper use of scuba equipment can result in serious injury. You must be thoroughly instructed in its use under direct supervision of a qualified instructor to use it safely.

If you have any additional questions regarding this Medical Statement or the Medical Questionnaire section, review them with your instructor before signing.

Divers Medical Questionnaire

To the Participant:

The purpose of this Medical Questionnaire is to find out if you should be examined by your doctor before participating in recreational diver training. A positive response to a question does not necessarily disqualify you from diving. A positive response means that there is a preexisting condition that may affect your safety while diving and you must seek the advice of your physician prior to engaging in dive activities.

____ Could you be pregnant, or are you attempting to become pregnant?

____ Are you presently taking prescription medications? (with the exception of birth control or anti-malarial)

____ Are you over 45 years of age and can answer YES to one or more of the following?

- currently smoke a pipe, cigars or cigarettes
- have a high cholesterol level
- have a family history of heart attack or stroke
- are currently receiving medical care
- high blood pressure
- diabetes mellitus, even if controlled by diet alone

Have you ever had or do you currently have...

____ Asthma, or wheezing with breathing, or wheezing with exercise?

____ Frequent or severe attacks of hayfever or allergy?

____ Frequent colds, sinusitis or bronchitis?

____ Any form of lung disease?

____ Pneumothorax (collapsed lung)?

____ Other chest disease or chest surgery?

____ Behavioral health, mental or psychological problems (Panic attack, fear of closed or open spaces)?

____ Epilepsy, seizures, convulsions or take medications to prevent them?

____ Recurring complicated migraine headaches or take medications to prevent them?

____ Blackouts or fainting (full/partial loss of consciousness)?

____ Frequent or severe suffering from motion sickness (seasick, carsick, etc.)?

Please answer the following questions on your past or present medical history with a YES or NO. If you are not sure, answer YES. If any of these items apply to you, we must request that you consult with a physician prior to participating in scuba diving. Your instructor will supply you with an RSTC Medical Statement and Guidelines for Recreational Scuba Diver's Physical Examination to take to your physician.

____ Dysentery or dehydration requiring medical intervention?

____ Any dive accidents or decompression sickness?

____ Inability to perform moderate exercise (example: walk 1.6 km/one mile within 12 mins.)?

____ Head injury with loss of consciousness in the past five years?

____ Recurrent back problems?

____ Back or spinal surgery?

____ Diabetes?

____ Back, arm or leg problems following surgery, injury or fracture?

____ High blood pressure or take medicine to control blood pressure?

____ Heart disease?

____ Heart attack?

____ Angina, heart surgery or blood vessel surgery?

____ Sinus surgery?

____ Ear disease or surgery, hearing loss or problems with balance?

____ Recurrent ear problems?

____ Bleeding or other blood disorders?

____ Hernia?

____ Ulcers or ulcer surgery ?

____ A colostomy or ileostomy?

____ Recreational drug use or treatment for, or alcoholism in the past five years?

The information I have provided about my medical history is accurate to the best of my knowledge. ***I agree to accept responsibility for omissions regarding my failure to disclose any existing or past health condition.***

Signature	Date	Signature of Parent or Guardian	Date

PRODUCT NO. 10063 (Rev. 9/01) Ver. 2.0

Page 1 of 6

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Appendix B

Multidimensional Fatigue Inventory

Multidimensional Fatigue Inventory
*** MFI-20 ***

Instructions:

Please respond to the following statements with respect to how you are feeling right now. There is, for example, the statement

"I FEEL RELAXED"

If you think that this is entirely true, that indeed you are feeling relaxed right now, please, place an X in the extreme left box; like this:

yes, that is true	X					no, that is not true

The more you disagree with the statement, the more you should place an X in the direction of "no, that is not true". Please, provide an answer for all statements.

---

1. I feel fit.	Yes, that is true						No, that is not true
2. Physically, I feel only able to do a little.	Yes, that is true						No, that is not true
3. I feel very active.	Yes, that is true						No, that is not true
4. I feel like doing all sorts of nice things.	Yes, that is true						No, that is not true
5. I feel tired.	Yes, that is true						No, that is not true
6. I think I do a lot in a day.	Yes, that is true						No, that is not true
7. When I am doing something, I can keep my thoughts on it.	Yes, that is true						No, that is not true
8. Physically, I can take on a lot.	Yes, that is true						No, that is not true
9. I dread having to do things.	Yes, that is true						No, that is not true
10. I think I do very little in a day.	Yes, that is true						No, that is not true
11. I can concentrate well.	Yes, that is true						No, that is not true
12. I am rested.	Yes, that is true						No, that is not true
13. It takes a lot of effort to concentrate on things.	Yes, that is true						No, that is not true
14. Physically, I feel I am in bad condition.	Yes, that is true						No, that is not true
15. I have a lot of plans.	Yes, that is true						No, that is not true
16. I tire easily.	Yes, that is true						No, that is not true
17. I get little done.	Yes, that is true						No, that is not true
18. I don't feel like doing anything.	Yes, that is true						No, that is not true
19. My thoughts easily wander.	Yes, that is true						No, that is not true
20. Physically I feel I am in excellent condition.	Yes, that is true						No, that is not true

Thank you very much for your cooperation

Appendix C

100 mm Visual Analogue Scale

<u>Fatigue</u>: Complaints of being tired, experiencing a lack of sleep or a generalized tiredness
– *Diver's Alert Network, 2006*

How fatigued are you feeling <u>right now</u>?

Place a vertical mark along the line below indicating your fatigue level.

No fatigue ◆————————————————————◆ Very fatigued

Appendix D

Diver Health Survey

Please complete all questions at the end of your work day. Place a tick in the one box that most closely describes your health **since your last dive yesterday** (please include **all health problems**, even if they are not related to diving).

1. Fill in this information about your diving today.

time	month	day	year	number of dives yesterday	hours since finished diving yesterday	your name

2. In general, how would you describe your health since your last dive?

poor ☐
fair ☐
good ☐
excellent ☐

3. Did any health problems begin on the day of your last dive (today)?

no ☐
yes, during or within one hour after any dive ☐
yes, between one and six hours after last dive ☐
yes, more than six hours after last dive ☐

4. How much pain have you had on average in your knees, hips, elbows, shoulders or other joints since your last dive?

severe ☐
moderate ☐
mild ☐
none ☐

5. How much of the time since your last dive you had any numbness, tingling, burning, or other unusual feelings on any part of your body?

none of the time ☐
some of the time ☐
most of the time ☐
all of the time ☐

6. How much of the time since your last dive have you had a rash or itch?

none of the time ☐
some of the time ☐
most of the time ☐
all of the time ☐

7. How much of the time since your last dive have you felt full of energy?

none of the time ☐
some of the time ☐
most of the time ☐
all of the time ☐

8. Since your last dive, how much has your health interfered with your normal activities, for instance climbing out of a boat or lifting equipment?

extreme amount ☐
quite a bit ☐
a little bit ☐
not at all ☐

9. How much of the time today have you had difficulty with your balance, for instance standing with your eyes closed or standing aboard a moving boat?

none of the time ☐
some of the time ☐
most of the time ☐
all of the time ☐

10. Since your last dive, how much difficulty have you had with activities that involve concentration, for instance this survey?

extreme amount ☐
quite a bit ☐
a little bit ☐
not at all ☐

Has your health changed in any other way since your last dive? ____________________

Appendix E

Perceived Thermal Comfort and Workload Questionnaire

POST-DIVE
REPORT

DATE:		**NAME:**		**1st Dive**	**2nd Dive**
THERMAL COMFORT (Cold 1 - 5 Warm)					
WORKLOAD DURING DIVE (Light 1 - 5 Hard)					
PROBLEMS (Equalization, Vertigo, Out of Air, Buoyancy, Shared Air, Rapid Ascent, Seasickness, Other, None)					
EQUIPMENT MALFUNCTION (Mask, Fins, Weight Belt, BC, Thermal Protection, Computer, Depth Gauge, Pressure Gauge, Regulator, None)					
DRESS (Drysuit, Wetsuit)					
ADDITIONAL COMMENTS:					

Appendix F

Test Session Datasheet

Test Session Date: ____________________

Dive Site: ____________________

Air Temperature: ____________________

Water Temperature: ____________________

Swell Height: ____________________

Wind: ____________________

Tide: ____________________

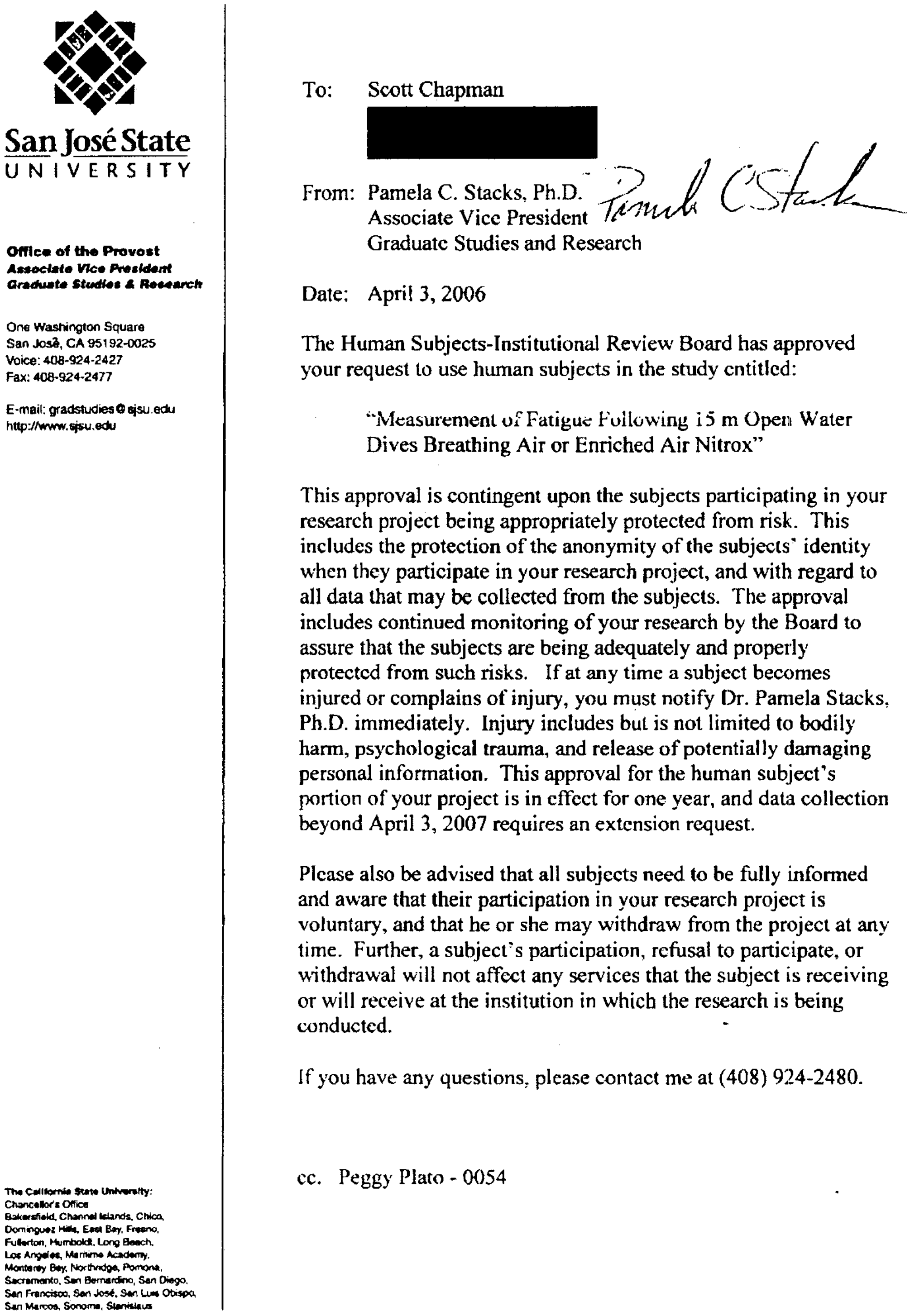
	Participant	ID	T#	Pre-Test Time	Tank Pair	Dive No.	Tank #	ft3	Tank PSI		Dive Time		TBT	Max Depth	Laps	Post-Test Time
									Start	End	Start	End				
TEAM 1			☐													
			☐													
			☐													
			☐													

Session 1 **Session 2**

Participant		Water	Bagel	Yogurt	Banana	Granola Bar	Water	Bagel	Yogurt	Banana	Granola Bar
	PRE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	SIT	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	POST	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	PRE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	SIT	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	POST	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Appendix G

Human Subjects-Institutional Review Board Approval



San José State
UNIVERSITY

Office of the Provost
Associate Vice President
Graduate Studies & Research

One Washington Square
San José, CA 95192-0025
Voice: 408-924-2427
Fax: 408-924-2477

E-mail: gradstudies@sjsu.edu
http://www.sjsu.edu

To: Scott Chapman
[redacted]

From: Pamela C. Stacks, Ph.D. Pamela C Stacks
Associate Vice President
Graduate Studies and Research

Date: April 3, 2006

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

> "Measurement of Fatigue Following 15 m Open Water Dives Breathing Air or Enriched Air Nitrox"

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to all data that may be collected from the subjects. The approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Dr. Pamela Stacks, Ph.D. immediately. Injury includes but is not limited to bodily harm, psychological trauma, and release of potentially damaging personal information. This approval for the human subject's portion of your project is in effect for one year, and data collection beyond April 3, 2007 requires an extension request.

Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services that the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact me at (408) 924-2480.

cc. Peggy Plato - 0054

The California State University:
Chancellor's Office
Bakersfield, Channel Islands, Chico,
Dominguez Hills, East Bay, Fresno,
Fullerton, Humboldt, Long Beach,
Los Angeles, Maritime Academy,
Monterey Bay, Northridge, Pomona,
Sacramento, San Bernardino, San Diego,
San Francisco, San José, San Luis Obispo,
San Marcos, Sonoma, Stanislaus

Appendix H

Agreement to Participate in Research

San José State
UNIVERSITY

**College of Applied
Sciences and Arts**

Department of Kinesiology

One Washington Square
San José, CA 95192-0054
Voice: 408-924-3010
Fax: 408-924-3053

Agreement to Participate in Research

Responsible Investigator(s): Scott Chapman, B.S.
Peggy Plato, Ph. D.

Title of Protocol: Measurement of fatigue following 18 msw open water dives breathing air or EAN36

I have been asked to participate in a research study investigating fatigue following SCUBA dives using air or 36% Enriched Air Nitrox (EAN36) as the breathing gas. Testing will take place in an open water environment in Monterey, CA.

I understand that a trained Fill Station Operator (FSO) will analyze and record percent of oxygen in all EAN36 cylinders utilized during a test session. I acknowledge that the FSO will ensure that all EAN36 cylinders contain between 35-37% oxygen, and that a second, trained individual, will verify the EAN36 mix. I recognize that the maximum operating depth (MOD) of EAN36 is 28 msw (95 fsw) and that the test protocol only requires diving to maximum of 18 msw (60 fsw).

I will be asked to participate in two testing sessions. For each testing session, I will report to San Carlos Beach in Monterey, CA. A testing session will consist of two square-profile 30 minute SCUBA dives, separated by a one hour surface interval, at a maximum depth of 18 msw (60 fsw). I understand that air will be used as the breathing gas for both dives in one testing session and EAN36 in the other in random order. I understand that I must always dive with a buddy. I will perform my second test no less than 48 hours after my first.

I understand that I will be asked to refrain from heavy exercise, smoking, SCUBA diving, non-prescription drugs, and drinking alcohol or caffeinated beverages for 24 hours prior to each testing session. I will also be asked not to eat for 8 hours prior to each testing session.

I understand that there are risks associated with SCUBA diving. Although the testing session dive profiles fall within recreational no decompression stop limits, there is still a potential risk of developing decompression illness and/or other pressure-related injuries. I will follow the prescribed dive plan, will ascend no faster than 9 m/min (30 ft/min), and will perform a 3 minute safety stop at 4.6 msw (15 fsw) to reduce the risk of injury.

Initial ________

The California State University:
Chancellor's Office
Bakersfield, Channel Islands, Chico,
Dominguez Hills, East Bay, Fresno,
Fullerton, Humboldt, Long Beach,
Los Angeles, Maritime Academy,
Monterey Bay, Northridge, Pomona,
Sacramento, San Bernardino, San Diego,
San Francisco, San José, San Luis Obispo,
San Marcos, Sonoma, Stanislaus

San José State
UNIVERSITY

**College of Applied
Sciences and Arts**

Department of Kinesiology

One Washington Square
San José, CA 95192-0054
Voice: 408-924-3010
Fax: 408-924-3053

The occurrence of a serious risk, such as a decompression illness or drowning, is rare; however, if I report any unusual symptoms, including nausea, vomiting, headaches, dizziness, numbness and tingling, and chest pain, the test will be stopped and I will be placed on 100% oxygen. Paramedics (911) will be called under such circumstances and for any other life-threatening emergency. Cardiopulmonary resuscitation (CPR) and/or an automated external defibrillator will be used, if needed, to treat life-threatening cardiac arrhythmias. Participants who experience minor, non-diving related injuries will be encouraged to seek medical attention, as needed, at their own expense.

I may benefit from this study by learning how different breathing gases affect postdive fatigue levels commonly experienced after SCUBA diving.

I understand that the results of this study may be published or presented, but I will not be identified unless I give expressed written permission for the researcher to do so.

I understand I will not be financially compensated for participating in this study.

Questions I have about this research may be addressed to Scott Chapman (sdchap@pacbell.net). Complaints about the research may be presented to V. Gregory Payne, P.E.D., Kinesiology Department Chair (408) 924-3010. Questions about research, subjects' rights, or research-related injury may be presented to Pamela Stacks, Ph.D., Associate Vice President, Graduate Studies and Research, at (408) 924-2480.

No service of any kind, to which I am otherwise entitled, will be lost or jeopardized if I choose to "not participate" in the study.

My consent is being given voluntarily. I may refuse to participate in the entire study or in any part of the study. I am aware of the possible risks and discomforts associated with testing. The procedures, discomforts, and risks were verbally explained to me. If I decide to participate in the study, I am free to withdraw at any time without any negative effect on my relations with San Jose State University.

I have received a signed and dated copy of this consent form.

- The signature of a subject on this document indicates agreement to participate in the study.
- The signature of a researcher on this document indicates agreement to include the above named subject in the research and attestation that the subject has been fully informed of his or her rights.

Signature Date

Investigator's Signature Date

The California State University:
Chancellor's Office
Bakersfield, Channel Islands, Chico,
Dominguez Hills, East Bay, Fresno,
Fullerton, Humboldt, Long Beach,
Los Angeles, Maritime Academy,
Monterey Bay, Northridge, Pomona,
Sacramento, San Bernardino, San Diego,
San Francisco, San José, San Luis Obispo,
San Marcos, Sonoma, Stanislaus

Appendix I

Pretest Instructions

Thank you for choosing to participate in the study: Measurement of fatigue following 18 msw open water dives breathing air or EAN36. Your participation will further enhance knowledge in diving physiology and potentially lead to increased dive safety.

This study involves two test sessions consisting of two SCUBA dives each. The test sessions will be separated by a minimum of 48 hours. You must provide your own SCUBA gear including appropriate thermal protection (7mm wetsuit, or a drysuit). Minimum SCUBA gear requirements include: *Mask, Fins, Snorkel, Weight System, Buoyancy Compensator, Submersible Pressure Gauge, Dive Timer, Depth Gauge with maximum depth recorder, and an Alternate Air Source (i.e., octopus regulator).* Dive computers are recommended. Tanks will be provided.

In an effort to ensure collection of reliable data, please adhere to the following pretest instructions:

1. Refrain from heavy exercise 24 hours prior to each test session.
2. Refrain from smoking 24 hours prior to each test session.
3. Refrain from SCUBA diving 24 hours prior to each test session.
4. Refrain from non-prescription drugs 24 hours prior to each test session.
5. Refrain from drinking alcohol 24 hours prior to each test session.
6. Refrain from drinking caffeinated beverages 24 hours prior to each test session.
7. Refrain from eating 8 hours prior to each test session (snacks will be provided during test sessions).
8. Use the same gear configuration for all test sessions including:
    a. Thermal protection (i.e., wetsuit, drysuit (including undergarments), gloves, hood, and booties)
    b. Mask, fins, snorkel, weight, and buoyancy compensator
    c. Dive computer

I have read the pre-test instructions listed above and agree to comply with the instructions.

Signature: ____________________________ Date: ____________

Appendix J

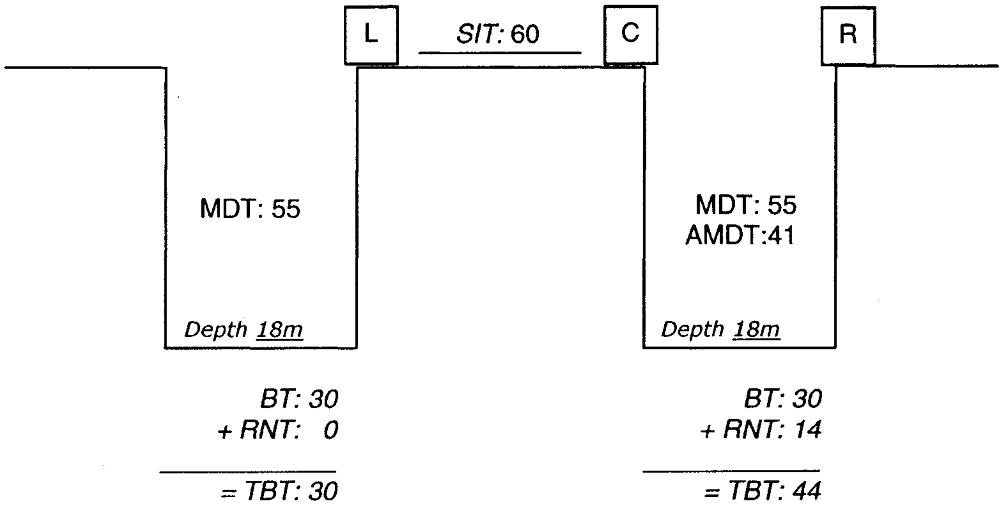
Marine Forecasts

Date	Wind	Wind Waves	Swell
October 1, 2006	W 5 KT	1 FT OR LESS	NW 2 TO 4 FT AT 10 SECONDS AND SW 1 TO 3 FT AT 13 SECONDS
November 16, 2006	W 5 TO 10 KT	1 FT	NW 4 TO 8 FT AT 11 SECONDS
December 19, 2006	SE 5 KT...BECOMING SW IN THE AFTERNOON	1 FT	NW 3 TO 7 FT AT 13 SECONDS
January 10, 2007	NW 15 TO 25 KT	3 TO 5 FT	NW 4 TO 9 FT AT 12 SECONDS
January 12, 2007	N TO NE 5 TO 15 KT EXCEPT 10 TO 20 KT OUTER WATERS	1 TO 3 FT	NW 5 TO 9 FT AT 11 SECONDS
January 19, 2007	E 5 KT	1 FT OR LESS	NW 2 TO 6 FT AT 11 SECONDS
January 26, 2007	SE 5 KT	1 FT OR LESS	W 5 TO 10 FT AT 13 SECONDS
February 2, 2007	NE 5 KT	1 FT	W 4 TO 8 FT AT 13 SECONDS
February 16, 2007	NW 5 TO 15 KT. BECOMING W 5 KT IN THE AFTERNOON	1 TO 3 FT	W SWELL 3 TO 8 FT AT 12 SECONDS
April 13, 2007	Not recorded	Not recorded	Not recorded
April 29, 2007	W TO SW 5 TO 10 KT	1 FT	NW SWELL 4 TO 9 FT AT 13 SECONDS

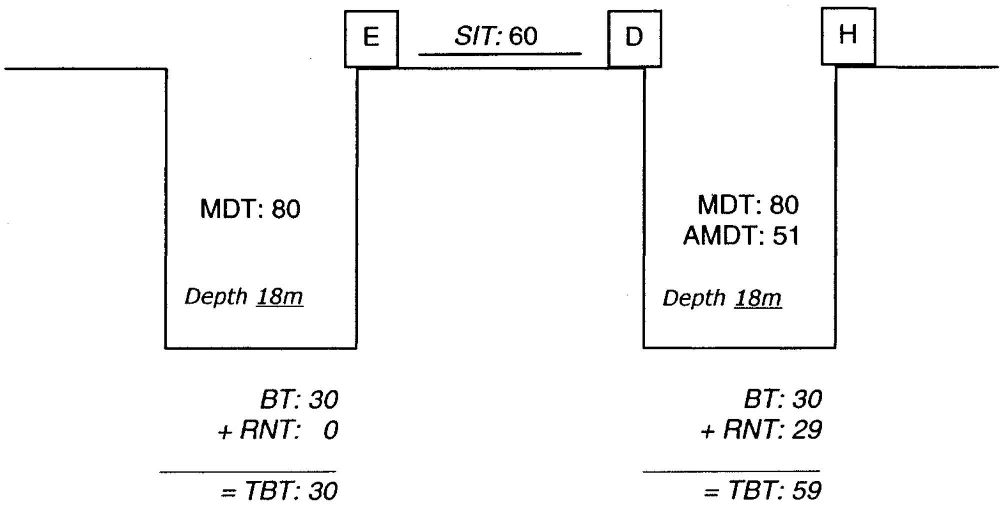
Appendix K

Dive Plan Overview

AIR (based on PADI RDP Table)



EAN36 (based on National Association of Underwater Instructors EAN36 Table)



MDT: Maximum Dive Time
BT: Bottom Time
RNT: Residual Nitrogen Time
TBT: Total Bottom Time
AMDT: Adjusted Maximum Bottom Time
SIT: Surface Interval Time

Appendix L

Fill Log Plan

Test Session 1 **Test Session 2**

				EAN Analysis								EAN Analysis		
					Analyzed By								Analyzed By	
T Set	Gas	Fill Date	Tank #	%O_2	1st	2nd	Participant	T Set	Gas	Fill Date	Tank #	%O_2	1st	2nd
1	AIR			☒	☒	☒	1	12	EAN36					
2	EAN36						2	13	AIR			☒	☒	☒
3	AIR			☒	☒	☒	3	14	EAN36					
4	AIR			☒	☒	☒	4	15	EAN36					
5	EAN36						5	16	AIR			☒	☒	☒
6	AIR			☒	☒	☒	6	17	EAN36					
7	AIR			☒	☒	☒	7	18	EAN36					
8	EAN36						8	19	AIR			☒	☒	☒
9	EAN36						9	20	AIR			☒	☒	☒
10	EAN36						10	21	AIR			☒	☒	☒
11	EAN36						11	22	AIR			☒	☒	☒

Appendix M

Raw Data

ID	Dive #	Gas	T (degC)	Max Depth	Bottom Time (min)	Gas Used (psi)	Gas Used (L)	Laps	Speed (m/min)	Swim Time (min)	Thermal Comfort	Workload	Dress	Descent Rate	Ascent Rate
NV01	1	AIR	14.4	58	29	1600	1448.96	9	16.46	20	3	1	w	15	6
	2	AIR	14.4	57	30	1500	1358.4	9	15.68	21	3	1	w	13	7
	3	EAN	13.3	56	30	1950	1765.92	10	17.42	21	2	1	w	15	9
	4	EAN	13.3	55	31	2000	1811.2	11	17.49	23	3	1	w	14	8
CF02	1	EAN	15	57	29	1800	1630.08	9	16.46	20	4	2	w	13	8
	2	EAN	15	57	30	1900	1720.64	9	15.68	21	5	1	w	13	6
	3	AIR	13.9	56	29	1700	1539.52	10	16.63	22	5	3	w	14	10
	4	AIR	13.9	56	30	1900	1720.64	11	18.29	22	5	1	w	13	7
MT03	1	AIR	13.3	56	27	2050	1856.48	10	16.63	22	3	2	w	15	8
	2	AIR	13.3	55	28	1800	1630.08	11	20.12	20	3	2	w	14	8
	3	EAN	10.6	55	28	2100	1901.76	9	16.46	20	1	3	w	15	6
	4	EAN	10	54	30	1900	1720.64	11	18.29	22	1	1	w	15	6
GR04	1	AIR	11.1	55	31	1800	1584.8	9	17.32	19	3.5	3	w	13	7
	2	AIR	11.1	56	34	1900	1539.52	9	18.29	18	2.5	3	w	12	8
	3	EAN	12.8	58	29	1750	1630.08	10	19.25	19	4	2	w	12	6
	4	EAN	12.8	56	33	1700	1720.64	9	17.32	19	2	2	w	11	5
LR05	1	EAN	12.2	58	29	1290	1168.224	10	20.32	18	3	1	w	21	7
	2	EAN	12.2	57	33	1550	1403.68	9	16.46	20	2	2	w	14	6
	3	AIR	11.1	59	31	1460	1322.176	10	18.29	20	4	1	w	21	7
	4	AIR	11.1	57	32	1535	1390.096	10	17.42	21	3	1	w	13	5
DH06	1	AIR	11.1	56	31	1900	1720.64	9	17.32	19	5	2	d	14	5
	2	AIR	11.1	56	33	2000	1811.2	9	17.32	19	4	2	d	13	6
	3	EAN	11.1	60	31	1750	1584.8	10	17.42	21	5	2	d	21	7
	4	EAN	11.1	57	32	2000	1811.2	10	18.29	20	4	2	d	13	5
CS07	1	AIR	11.1	57	29	1700	1539.52	9	14.96	22	3	2	w	15	9
	2	AIR	11.1	56	29	2200	1992.32	9	14.96	22	2	2	w	16	7
	3	EAN	11.7	60	27	1500	1358.4	7	14.23	18	3.5	2	w	14	6
	4	EAN	11.7	60	30	1800	1630.08	9	15.68	21	4	2	w	15	8
PC08	1	EAN	11.1	56	29	1700	1539.52	9	14.96	22	3	1	w	14	7
	2	EAN	11.1	55	30	1550	1403.68	9	14.96	22	3	2	w	16	7
	3	AIR	11.7	61	27	1400	1267.84	7	14.23	18	4	1	w	14	6
	4	AIR	11.7	60	30	1700	1539.52	9	15.68	21	3	1	w	15	8
RS09	1	EAN	11.7	56	32	1900	1720.64	12	19.08	23	4	2	w	15	6
	2	EAN	11.7	55	32	1900	1720.64	12	18.29	24	3	1	w	14	6
	3	AIR	11.7	59	30	1900	1720.64	12	19.08	23	3	4	w	23	7
	4	AIR	11.7	58	30	2000	1811.2	11.5	18.29	23	4	3	w	15	5
SC10	1	EAN	11.7	56	32	1750	1584.8	12	19.08	23	2	2	w	15	6
	2	EAN	11.7	55	32	2200	1992.32	12	18.29	24	1	2	w	14	6
	3	AIR	11.7	59	30	2050	1856.48	12	19.08	23	2	3	w	23	7
	4	AIR	11.7	58	30	1850	1675.36	11.5	18.29	23	2	2	w	15	5
TM11	1	EAN	10.6	55	30	2300	2082.88	9	16.46	20	1	1	d	15	7
	2	EAN	10	54	28	1700	1539.52	11	18.29	22	0.5	1	d	15	6
	3	AIR	11.1	53	31	1600	1448.96	10	15.24	24	2	1.5	d	15	5
	4	AIR	11.1	54	32	1500	1358.4	10	17.42	21	2	1	d	15	7

Multidimensional Fatigue Inventory

		MFI AIR		MFI EAN	
ID	Category	$\mathrm{PRE}_{\mathrm{AIR}}$	$\mathrm{POST}_{\mathrm{AIR}}$	$\mathrm{PRE}_{\mathrm{EAN}}$	$\mathrm{POST}_{\mathrm{EAN}}$
NV01	GF	8	8	10	10
CF02	GF	8	9	6	10
MT03	GF	13	8	9	13
GR04	GF	10	14	7	9
LR05	GF	8	7	8	7
DH06	GF	9	8	7	7
CS07	GF	4	8	5	7
PC08	GF	6	7	8	8
RS09	GF	8	10	6	8
SC10	GF	7	8	7	9
TM11	GF	9	12	12	12
NV01	MF	4	5	12	10
CF02	MF	6	13	9	9
MT03	MF	12	15	9	11
GR04	MF	11	12	10	11
LR05	MF	7	7	6	7
DH06	MF	4	4	4	4
CS07	MF	6	8	7	8
PC08	MF	7	8	10	10
RS09	MF	5	11	4	5
SC10	MF	5	5	4	7
TM11	MF	8	9	8	9
NV01	PF	12	8	13	12
CF02	PF	4	13	5	9
MT03	PF	10	8	9	9
GR04	PF	9	9	5	7
LR05	PF	7	7	5	5
DH06	PF	5	8	5	5
CS07	PF	4	7	5	5
PC08	PF	10	6	6	6
RS09	PF	5	6	5	6
SC10	PF	5	8	5	7
TM11	PF	10	11	11	10

Visual Analogue Scale

	VAS AIR		VAS EAN36	
ID	PRE	POST	PRE	POST
NV01	23.1	18.3	43	32
CF02	37	76	25.4	54
MT03	36.5	31	64.5	60
GR04	14	66	46	73
LR05	44	30	25.5	38
DH06	33	38.5	18	26
CS07	8	28	7	27
PC08	3	40	0	37
RS09	42	12.5	17	9
SC10	16.5	35.5	6	32
TM11	24	20	46.5	77.5

Diver Health Survey

ID	?	AIR	EAN36
NV01	1	2	1
	2	0	0
	3	1	0
	4	0	0
	5	0	0
	6	2	0
	7	0	0
	8	0	0
	9	0	0
	10	1	0
CF02	1	1	0
	2	0	0
	3	0	0
	4	0	0
	5	0	0
	6	1	1
	7	1	0
	8	0	0
	9	1	1
	10	0	0
MT03	1	1	0
	2	0	0
	3	0	0
	4	0	0
	5	0	0
	6	2	1
	7	0	0
	8	0	0
	9	0	0
	10	0	0
LR05	1	0	0
	2	0	0
	3	0	0
	4	0	0
	5	0	0
	6	1	1
	7	0	0
	8	0	0
	9	0	0
	10	0	0
DH06	1	1	1
	2	0	0
	3	0	0
	4	0	0
	5	0	0
	6	1	1
	7	0	0
	8	0	0
	9	0	0
	10	0	0
CS07	1	0	1
	2	0	0
	3	0	0
	4	0	0
	5	0	0
	6	2	1
	7	0	0
	8	0	0
	9	1	0
	10	1	0
PC08	1	1	1
	2	0	0

	3	0	0
	4	0	0
	5	0	0
	6	1	1
	7	0	0
	8	0	0
	9	0	0
	10	0	0
RS09	1	1	1
	2	0	0
	3	1	0
	4	0	0
	5	1	1
	6	0	0
	7	0	0
	8	0	0
	9	1	0
	10	1	1
SC10	1	0	0
	2	0	0
	3	0	0
	4	0	0
	5	0	0
	6	0	0
	7	0	0
	8	0	0
	9	0	0
	10	0	0
TM11	1	0	0
	2	0	0
	3	0	0
	4	0	0
	5	0	0
	6	1	1
	7	0	0
	8	0	0
	9	0	0
	10	0	0