Screening for oxygen sensitivity in U.S. Navy combat swimmers


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Walters KC, Gould MT, Bachrach EA, Butler FK Jr. Screening for oxygen sensitivity in U.S. Navy combat swimmers. Undersea Hyper Med 2000, 27(1):21–26.—The United States Naval Special Warfare Community uses oxygen tolerance testing to screen Navy combat swimmer candidates for sensitivity to the toxic effects of hyperbaric oxygen (HBO₂). Between 1976 and 1997, 6,250 oxygen-tolerance tests were performed at the Naval Special Warfare Center and Naval Special Warfare Group One. Our review of these data found only six episodes of O₂ toxicity for an incidence of 0.096%, an incidence considerably lower than the rate of 1.9% reported in an earlier review using data from the Naval Safety Center. Additionally, we reviewed data from the Naval Safety Center from 1986 to 1997 and found only one episode of O₂ toxicity among 157,930 LAR V dives. Many factors other than individual sensitivity to HBO₂ may contribute to the occurrence of O₂ toxicity episodes during combat swimmer operations. The authors conclude that O₂ tolerance testing of U.S. Navy SEAL candidates is not a useful screening test and recommend discontinuation of this test.

central nervous system oxygen toxicity, oxygen tolerance testing

The first use of closed-circuit oxygen underwater breathing apparatuses (UBAs) to conduct clandestine combat swimmer attacks against hostile ships occurred during World War II. Accompanying this new employment of military divers as an offensive weapon was an increased realization of the danger of convulsions and other symptoms of central nervous system (CNS) dysfunction as a result of the toxic effects of hyperbaric oxygen (HBO₂). This led to the pioneering research on CNS oxygen toxicity conducted by Professor Donald in the United Kingdom (1).

Donald (1) observed that the establishment of safe O₂ exposure limits for divers was made more difficult by the presence of marked inter-individual and intra-individual variability. An exposure to 100% O₂ at 90 ft saw CNS O₂ toxicity occur in one individual after only 6 min, whereas another diver was able to tolerate the same exposure for 96 min before the onset of symptoms (1). In another experiment, a diver was immersed at a pressure equivalent to 50 feet of sea water (fsw) breathing 100% O₂ on three different occasions. On the first exposure, a convolution occurred after only 12 min. On the next dive, the diver remained at depth for 100 min without symptoms, whereas on the third dive a convolution occurred at 32 min. (If these trials seem extreme in retrospect, it helps to remember that they took place during World War II and that there were much worse places to be at that time than in Dr. Donald’s studies.) On the basis of his experimental work, Donald (1) recommended that closed-circuit O₂ diving be limited to depths of 25 ft or shallower.

Studies performed at the United States Navy Experimental Diving Unit (NEDU) in the 1940s and 1950s resulted in the exposure limits for closed-circuit O₂ divers shown in Table I (2,3). In an effort to screen for divers who were unusually sensitive to the toxic effects of HBO₂, the U.S. Navy required all candidates for diver training to undergo an oxygen tolerance test (OTT) consisting of 30 min of breathing 100% O₂ while at rest in a dry hyperbaric chamber at a depth of 60 fsw. Individuals who developed symptoms of O₂ toxicity during the OTT were not allowed to enter Navy diving programs.

In 1981, the Naval Special Warfare (NSW) community requested that NEDU study the feasibility of extending the O₂ exposure limits in Table 1 and, if possible, incorporate into the exposure limits the ability to make brief excursions to a deeper depth. Over the next 3 yr, NEDU conducted the largest series of HBO₂ exposures ever performed on immersed, exercising divers. The results of this series of trials have been described previously (4–6) and resulted in a recommendation that O₂ exposure limits
for closed-circuit \( \text{O}_2 \) scuba divers be significantly extended to those shown in Tables 2 and 3 (7). These new limits were subsequently approved by the Naval Sea Systems Command, implemented in NSW combat swimmer operations, and incorporated into the U.S. Navy Diving Manual (8).

At the time that these new limits were published, there was considerable discussion at NEDU over the use of the OTT. Several divers who participated in the \( \text{O}_2 \) dives of 1982–1984 were found to be unusually sensitive to \( \text{O}_2 \) despite their having passed the OTT before dive training. Two of these divers experienced several convulsions within the new limits that had just been approved, despite these exposures proving safe for all of the other divers in the trials. This raised the question of whether the OTT was useful in identifying sensitive divers because of the intra-individual variability described by Donald. This question was addressed in a follow-on study (9) in which the OTT was given repeatedly to this group of sensitive divers to determine whether they would develop symptoms of CNS \( \text{O}_2 \) toxicity with repeated OTTs. None of these oxygen-sensitive divers developed CNS \( \text{O}_2 \) toxicity on any OTT (9). These data would seem to impugn the effectiveness of the OTT in identifying sensitive individuals, but a review of the Naval Safety Center’s data from the previous 10-yr experience with the OTT found that approximately 2% of those who took the OTT did, in fact, fail it. The authors of this study noted that the relatively low number of OTTs reported compared to the estimated number of new divers entering training each year suggested that the failure rate might be factiously high. There was also discussion concerning whether the OTT should be made more severe to identify a higher percentage of \( \text{O}_2 \)-sensitive individuals, but this was believed to be inadvisable because of ethical considerations (9). The recommendation of this paper, which was followed initially by the Navy, was that the OTT be left in place as a possibly helpful, although admittedly imperfect, screening tool.

The faults of the OTT as a screening test combined with the expense and the logistical burden of administering the OTT to all diving candidates caused the U.S. Navy to discontinue the use of the OTT for most diving candidates in the early 1990s. The NSW community, however, retained the OTT because of the high probability that an underwater convolution encountered by a free-swimming combat diver would result in his death.

The purpose of this paper is to re-evaluate the use of the OTT in the Naval Special Warfare community in light of two additional sources of data. The Naval Special Warfare Center and Naval Special Warfare Group One have conducted OTTs on a routine basis over the last 20 yr, and logs from these dives allow a much more accurate determination of the failure rate of the OTT. The Naval Safety Center maintains a database of all closed-circuit \( \text{O}_2 \) dives and reports of diving injuries to allow analysis of CNS \( \text{O}_2 \) toxicity injury rates for Naval Special Warfare LAR V dives.

This study examines these data with the intent of providing an updated recommendation regarding the continued use of the OTT.

**METHODS**

The OTT data were obtained through careful review of smooth diving logs maintained at the Naval Special Warfare Center (NSWC) and Naval Special Warfare Group One (NSWG-1), Coronado, CA. These handwritten logs are maintained at all navy hyperbaric facilities and account for all chamber dives. Log entries for each dive include the diving supervisor, chamber operator, inside tender, the names of chamber occupants, the
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The purpose of the dive, breathing mixture, the dive profile, and any complications. In all, 6,250 OTTs from 1976 to the present were reviewed by Diving Medical Officers (DMOs). Candidates receive a diving physical examination and their medical records are screened before the test for any disqualifying medical conditions. On the day of the test, they are questioned to ensure that they are feeling well before the OTT is administered. Candidates are then given a pre-dive brief of what to expect during the OTT, including the signs and symptoms of \( \text{O}_2 \) toxicity. The candidates are instructed to immediately report any symptoms suggestive of \( \text{O}_2 \) toxicity and are observed from within the chamber by an inside tender (usually an experienced diving medical technician) for signs of \( \text{O}_2 \) toxicity. Candidates who do not experience signs or symptoms of \( \text{O}_2 \) toxicity (visual disturbances, nausea, tinnitus, dizziness, irritability, muscle twitching, convolution, etc.) are found physically qualified for closed-circuit \( \text{O}_2 \) dive training. Those who exhibit muscle twitching or who experience a convolution are found to be not physically qualified for closed-circuit \( \text{O}_2 \) dive training. Candidates who exhibit equivocal signs or symptoms of CNS \( \text{O}_2 \) toxicity (signs other than muscle twitching or convulsions) are evaluated by a DMO who may or may not allow the candidate to retest. Retests are conducted no sooner than 72 h after the first test. Any recurrence of CNS \( \text{O}_2 \) toxicity signs or symptoms on subsequent testing will render the candidate not physically qualified.

A database query was also performed by the Naval Safety Center to determine the number of closed-circuit \( \text{O}_2 \) dives performed by Navy SEALs from 1986 to present, along with the number and description of any reported \( \text{O}_2 \) toxicity signs or symptoms.

In addition, DMOs from Australia, Canada, Israel, Denmark, Germany, and the United Kingdom were interviewed to determine what, if any, \( \text{O}_2 \) tolerance testing is performed among candidates preparing to enter training for closed-circuit \( \text{O}_2 \) dive training in their respective armed services.

RESULTS

Of the 6,250 OTTs conducted at NSWC and NSWG-1 from 1976 to present, only six (0.096%) of the candidates experienced signs or symptoms that were judged to represent \( \text{O}_2 \) toxicity. Three of these candidates reported muscle twitching (arm and leg), another complained of nausea and dizziness, one reported "ringing" in his ears, and one candidate experienced facial muscle twitching that rapidly progressed to a convolution.

The Naval Safety Center reported 157,930 LAR V dives with only one report of \( \text{O}_2 \) toxicity. The episode was described as "diver tried to claw to the surface and then went into convulsions, diagnosed as oxygen poisoning by Diving Medical Officer".

Of the six allied countries queried for use of an OTT, several reported utilization of hypercarbia recognition training, but only one, Germany, uses an OTT to screen candidates. The Germans use an OTT similar to the test described here and could not recall any candidate experiencing serious \( \text{O}_2 \) toxicity signs or symptoms during the test (personal communication Dr. Bettinghausen, German Naval Medical Institute, 1997).

DISCUSSION

Naval Special Warfare commands presently perform \( \text{O}_2 \) tolerance testing based on the premise that some individuals have an increased sensitivity to high partial pressures of oxygen, leading them to develop CNS \( \text{O}_2 \) toxicity earlier and/or at a lower partial pressure than the average diver. Without question, the identification and disqualification of such personnel before initiation of dive training would provide an increased margin of safety in combat swimmer operations.

Estimation of OTT failure rate. The presence of individuals with an increased sensitivity to \( \text{O}_2 \) toxicity was first noted by Donald (1), and more recently by Butler and associates (4–6). Our review of 6,250 OTTs performed during the time indicated found only six episodes of \( \text{O}_2 \) toxicity, for a failure rate of just 0.096%, a rate considerably lower than the failure rate of 1.9% noted in the review of 10 yr of Naval Safety Center data on \( \text{O}_2 \) tolerance tests done by Butler and Knafele (9). The authors of the latter study acknowledged that the 1,347 OTTs reported to the Naval Safety Center during the 10-yr period of their analysis represented a smaller number of tests than would be expected during this period and suggest this to be a result of under-reporting to the Naval Safety Center (9). The Naval Diving and Salvage Training Center (NDSTC) estimates the number of new divers entering training at their facility to range between 900 and 1,000 candidates each year. The NSWC receives between 600 and 700 candidates each year. Therefore the total number of dive candidates entering initial dive training each year at these two primary diver training sites is estimated to be between 1,500 and 1,700 (personal communication, NDSTC and NSWC, 1999). For the 10-yr period cited by Butler and Knafele (9) this represents between 15,000 and 17,000 OTTs, in contrast to the 1,347 reported to the Naval Safety Center, and supports the authors claim that under-reporting resulted in a
factitiously high OTT failure rate. This estimate does not account for possible decreases in the numbers of diving candidates that may have resulted from service-wide “downsizing” over the past decade. Diving supervisors may feel more compelled to report OTT failures than non-failures, because candidates who fail the OTT represent a greater liability than non-failures. Thus, gross under-reporting and a possible selection bias to report failures may account for the differences in OTT failure rates reported by Butler and Knaflec (9) and the current study.

Relationship of OTT to operational risk of O₂ toxicity: Having accepted that we are screening for individuals who are at increased risk for CNS O₂ toxicity, it is important to ascertain whether these individuals have an operationally significant condition. In other words, are these individuals truly unable to safely dive within the guidelines currently established for U.S. Navy diving, or is their increased sensitivity significant in the OTT but unlikely to produce toxicity episodes in an operational setting?

The data from the Naval Safety Center seems to demonstrate that reports of CNS O₂ toxicity during U.S. Navy closed-circuit dives are rare. However, the actual number of divers who experienced signs or symptoms of CNS O₂ toxicity during the reported period may be higher. The current reporting system only requires Naval Safety Center notification for mishaps that require hyperbaric treatment or result in a loss of five or more workdays. Some episodes of CNS O₂ toxicity may not have met these criteria and therefore gone unreported. The authors are unaware of any convulsions or deaths within the NSW community that have resulted from CNS O₂ toxicity during closed-circuit O₂ scuba diving. Both the effectiveness of O₂ tolerance testing in identifying “sensitive” personnel and our current accuracy in documenting operational O₂ toxicity episodes are therefore less than optimal.

As noted above, a single test does not accurately define O₂ sensitivity. A first-time successful passing of the test causes the protocol to define an individual as physically qualified or not “sensitive” to hyperoxia, despite the fact that there can be day-to-day variation in O₂ tolerance. This reliance on a single testing episode, combined with the low sensitivity of the OTT, may result in allowing individuals who are actually oxygen-sensitive members of the population to dive closed-circuit O₂ UBAs despite their theoretically greater risk. It is, however, logistically impractical to use multiple OTTs to more precisely define the average oxygen tolerance of each individual who is about to enter dive training. The Naval Special Warfare Center currently administers the OTT to approximately 200 dive candidates each year at a total cost of approximately 640 man hours of student and instructor time each year. To avoid the potential logistical burden of administering the OTT to 800 candidates each year, the OTT is now administered only to SEAL candidates who have successfully completed “Hell Week,” a very rigorous 5-day period during which the SEAL candidate performs almost continuous physical activity with only approximately 6 h of sleep during the whole period. The 25% of students who remain at this point have therefore already finished the most difficult 9 wk of SEAL training. Disqualifying SEAL candidates who have endured the rigors of Hell Week based on such an imperfect screening test is difficult to justify. Conducting multiple OTTs for each individual, however, to more precisely define an average O₂ tolerance, would increase costs dramatically.

In addition, at present, we do not have a standard that defines an operationally acceptable O₂ sensitivity. Even if multiple OTTs were to be performed in an attempt to define each candidate’s average O₂ susceptibility, the conditions under which the OTT is administered do not consider a number of modifying factors that may be encountered in the operational setting. One criticism that has often been leveled at the OTT is that it screens for O₂ sensitivity in divers who will be performing exercising, immersed dives by testing them in a dry chamber at rest. There may well be a poor correlation between the two types of exposures. Donald (1) described changes in oxygen tolerance with immersion, exercise, and water temperature. The suggestion has been made that divers should be tested in an immersed, exercising environment. This is not feasible because the candidates would be untrained as divers and not suitable for such a hazardous exposure for purposes of screening. Testing in a dry chamber at rest contributes to safety but detracts from the effectiveness of the OTT as a screening tool for operational diving.

Factors that modify operational risk: Even if the present OTT were an adequate screening test for an immersed, exercising diver, there is no guarantee that the individuals who are identified as being the most sensitive to the CNS toxic effects of O₂ in the standardized testing environment will be the ones at greatest risk for CNS O₂ toxicity in the combat swimmer’s operational environment, where canister failure, overexertion, fatigue, hyperventilation, and hypothermia may variably lower the diver’s threshold to the toxic effects of O₂. Some of these additional considerations are related to operator error. Despite the well-known exacerbating effect of high exercise levels on the incidence of CNS O₂ toxicity and the recommendation to swim at a relaxed, easy pace (7,8),
the diver may have been engaged in a competitive effort to finish a given course faster than his teammates. The diver may have used out-of-date or previously used CO₂ absorbent in packing his canister. Improper packing of the canister may result in gas “channeling” and subsequent premature canister failure. Hypercarbia is well known to result in a higher probability of CNS O₂ toxicity (10,11). In addition, the diver may have made an inadvertent depth excursion and exceeded the published exposure limits. Any of the above factors could result in a convulsion occurring on a closed-circuit O₂ dive even if an individual was not unusually O₂ sensitive.

The O₂ exposure limits currently used by the U.S. Navy have been criticized by Donald (12) as being too permissive. The potential for episodes of O₂ toxicity within the currently used operational limits is acknowledged (5,7,9), as is the potential for suffering an episode of decompression sickness despite strict adherence to decompression tables. The likelihood of toxicity on NSW closed-circuit dives has been significantly reduced by the modified Draeger LAR V purging procedures developed by Butler and Thalmann (13,14) shortly after the new limits were implemented. These new purging procedures decrease the surface O₂ fraction in the UBA breathing mix to an average of 74% in comparison to the more extensive purge procedures previously used that yielded a surface O₂ fraction of 85%. Using the new purge procedure, descent to 20 fsw increases the O₂ fraction to an average of 82%. Oxygen fractions at 20 fsw were not obtained for the more extensive 3-cycle fill/empty purge procedure (13). Because of the marked increase in the probability of CNS toxicity resulting from small increases in the partial pressure of oxygen in the range of 1.8—2.5 atm abs, this modification of the purge procedure was estimated by Harabin and her colleagues (15) to decrease the probability of O₂ toxicity by a factor as high as 40. This modified purge and the admonition to combat swimmers to swim at the shallowest depth that is tactically feasible (7,8) have probably contributed more significantly to the safety of NSW combat swimmer operations than the OTT.

Should OTT be modified or discontinued? As we look at the possibility of discontinuing a screening test that may also have contributed to the safety of U.S. Navy closed-circuit O₂ diving, we must acknowledge the concern that this action might place the diver at higher risk. Perhaps the imperfections of the OTT might be better addressed by making the test a more strenuous exposure. Although the use of a more severe OTT was investigated by Behnke and endorsed by Donald (12), the development of a more severe OTT to use in screening remains impractical. The need to know with some accuracy the percentage of the population that would develop CNS O₂ toxicity on a proposed new OTT would require a significant number of positive outcomes in the experimental trials. This would make the study a questionable one from a human protection standpoint. There remains the oft-mentioned difficulty of intra-individual variation and the potential that even a very sensitive individual might take the more strenuous OTT on a “good day” and not experience any symptoms of toxicity. Finally, the development of a more strenuous test that would disqualify, for example, the most O₂-sensitive 15% of NSW candidates would significantly reduce the pool of available candidates for SEAL training. This is a high price to pay for what is at best only a minimal increase in safety.

Efforts to maximize diving safety can be effected in the absence of an OTT by proper medical record screening, programs such as hypercarbia recognition training, and, most importantly, by continually educating NSW divers about diving procedures that can be employed to minimize the risk of CNS O₂ toxicity.

CONCLUSIONS AND RECOMMENDATIONS
1. The failure rate for the OTT as it is currently administered in NSW is 0.096%. This number is approximately 5% of the previously reported incidence of 1.9%, which was based on data from the Naval Safety Center.
2. The logistical burden of administering the OTT has caused testing to be currently conducted after the SEAL students have completed the most rigorous 9 wk of SEAL training. Disqualification of a SEAL candidate at that point in training should be based on clear and compelling evidence that the candidate is unfit to continue training. The OTT does not meet that standard.
3. Even if a more severe OTT were to be developed, intra-individual variability prevents any single screening test from being a reliable indicator of increased O₂ sensitivity.
4. Factors other than individual O₂ tolerance such as a high exercise rate, diver hypoventilation, canister failure, inadvertent depth excursions, inadequate thermal protection, or excessive purging of the UBA may contribute more to the risk of operational O₂ toxicity than individual sensitivity.
5. Naval Safety Center dive reporting procedures should be modified to document all suspected episodes of O₂ toxicity that occur on closed-circuit O₂ dives. This should include a reporting format that provides for
the maximum capture of pertinent data to facilitate accurate and reliable determinations of the CNS O₂ toxicity incidence in operational diving.

6. In light of items 1 through 4 above, the authors recommend discontinuation of the OTT as a screening test for Navy SEAL candidates.

Authors' Note: On 26 April 1999, the U.S. Naval Special Warfare Community discontinued the requirement for O₂ tolerance testing of U.S. Navy SEAL candidates. This decision was based, in part, on data presented in this report.

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REFERENCES