NSMRL TECHNICAL REPORT NO. 1223 13 June 2002

RECREATIONAL DIVER RESPONSES TO 600–2500 Hz WATERBORNE SOUND

By

D. M. Fothergill
D. Schwaller,
S.E. Forsythe,
E.A. Cudahy

Released by:
M. D. CURLEY, CAPT, MSC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
13-06-2002

2. REPORT TYPE
technical

3. DATES COVERED *(From - To)*
10-01-1999 to 9-30-2001

4. TITLE AND SUBTITLE
Recreational diver responses to 600-2500 Hz waterborne sound

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Fothergill, David M; Author
Schwaller, Derek ; Author
Forsythe, S E; Author
Cudahy, Edward A; Author

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
5913

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Submarine Medical
Research Laboratory
Naval Submarine Base New
London Box 900
Groton, CT 06349-5900

8. PERFORMING ORGANIZATION REPORT NUMBER
NSMRL Report # 1223

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Submarine Medical Resea
rch Laboratory
Naval Submarine Base New
Groton, CT 06349-5900

10. SPONSOR/MONITOR' S ACRONYM(S)
NSMRL

11. SPONSOR/MONITOR' S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
A Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Previous work (UHM, 27(Suppl): 18, 2000) investigated aversion to 600–2500 Hz waterborne sound (WBS) in US Navy divers. This study extends previous work by investigating the effects of 600–2420 Hz WBS on psychophysical and reaction time responses of recreational divers who have never previously experienced high levels of WBS. Nineteen male and two female military recreational divers volunteered. Subjects wore full 3-mm wet suits (without hood or gloves). Sound exposures consisted of 28-s pure tones at 600, 1000, 1750 and 2420 Hz, each presented at four sound pressure levels (SPL) ranging from 140 to 166 dB re 1 µPa. At least a 50% duty cycle was used. Subjects performed an underwater visual two-choice reaction time (RT) test while exposed to WBS. Following each sound exposure, divers rated loudness and body vibration for each signal on a 10-point category-ratio scale. Exposures to 600–2420 Hz WBS at SPLs up to 166 dB produce relatively low sensations of body vibration and result in small, but clinically insignificant, effects on a simple cognitive

15. SUBJECT TERMS
Divers; underwater acoustics; low frequency sound; waterborne sound (WBS); psychophysical; sound exposure;

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Ronald Joe
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	Same As Report	59	860-694-5157

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

RECREATIONAL DIVER RESPONSES TO 600–2500 Hz WATERBORNE SOUND

D.M. Fothergill,
D. Schwaller,
S.E. Forsythe,
E.A. Cudahy

Naval Submarine Medical Research Laboratory
Report # 1223

Work Unit # 5913

Approved and Released by:

M. D. CURLEY, CAPT, MSC, USN
Commanding Officer
NAVSUBMEDRSCHLAB

Approved for public release; distribution unlimited.

TABLE OF CONTENTS

SUMMARY PAGE

The Problem

Increasing use of high-powered sonar for detection of submarines has put the recreational diver at an increased risk of sound injury. In particular the development of new sonar systems for use in littoral waters raises the possibility that high levels of underwater sound may encroach on popular recreational dive sites. Currently, there is no guidance to indicate acceptable sound exposure levels for sonar systems that operate in the 500—2500 Hz frequency region.

Method

Nineteen male and two female recreational divers volunteered. Diving was conducted in a large fresh water pond (Dodge Pond, Niantic, CT). Subjects wore full 3-mm wet suits (without hood or gloves) and breathed surface supplied compressed air via a SCUBA regulator. Sound exposures consisted of 28-s pure tones at 600, 1000, 1750 and 2420 Hz, each presented at four sound pressure levels (SPL) ranging from 140 to 166 dB re 1 µPa[1]. At least a 50% duty cycle was used. Subjects performed an underwater visual two-choice reaction time (RT) test while exposed to waterborne sound. Following each sound exposure, divers rated loudness and body vibration for each signal on a 10-point category-ratio scale. If the divers could not tolerate the waterborne sound, they were instructed to follow specific abort procedures.

The Findings

There were no aborts or indications of panic resulting from the sound exposures. Furthermore, the subjects were able to continue with a simple two-choice underwater RT test with only minor decrements in the speed or accuracy of responding, even during the highest intensity sound exposure. Although sound exposures above 154 dB SPL resulted in high ratings of loudness and reports of vibration, physiological measures of heart rate (HR) and breathing frequency remained unaffected by the underwater sound exposures. This latter finding suggests that under the current experimental conditions the subjects did not exhibit a significant startle response to the underwater sound exposures.

The Application

The ultimate goal of this research is to provide input for setting guidelines for peacetime use of military active sonar that operate within the 500—2500 Hz frequency band. Based upon the loudness ratings it is recommended that the maximal acceptable SPL to 600–2500 Hz LFWBS for recreational divers be no higher than 154 dB re 1 µPa. This guideline will help ensure that operational use of low frequency sonar systems will cause no significant impact on the recreational diver.

ADMINISTRATIVE INFORMATION

This investigation was conducted under work unit # 5913 entitled: "Recreational diver responses to 600-2500 Hz waterborne sound." The views expressed in this report are those of the authors and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or the U.S. Government. This report was approved for publication on 13 June 2002 and has been designated as NavSubMedRschLab Report # 1223.

[1] Throughout this document, underwater sound pressure levels are given in decibels (dB) referenced to 1 µPa.

ABSTRACT

BACKGROUND: Previous work (UHM, 27(Suppl): 18, 2000) investigated aversion to 600–2500 Hz waterborne sound (WBS) in US Navy divers. This study extends previous work by investigating the effects of 600–2420 Hz WBS on psychophysical and reaction time responses of recreational divers who have never previously experienced high levels of WBS.

METHODS: Nineteen male and two female military recreational divers volunteered. Diving was conducted in a large fresh water pond (Dodge Pond, Niantic, CT). Subjects wore full 3-mm wet suits (without hood or gloves) and breathed surface supplied compressed air via a SCUBA regulator. Sound exposures consisted of 28-s pure tones at 600, 1000, 1750 and 2420 Hz, each presented at four sound pressure levels (SPL) ranging from 140 to 166 dB re 1 μPa. At least a 50% duty cycle was used. Subjects performed an underwater visual two-choice reaction time (RT) test while exposed to WBS. Following each sound exposure, divers rated loudness and body vibration for each signal on a 10-point category-ratio scale. If the divers could not tolerate the WBS, they were instructed to follow specific abort procedures.

RESULTS: No diver aborted a dive because of the sound exposure. RT was 3% slower during the sound presentations when compared with control trials (silence) ($p<0.05$). Neither frequency nor SPL significantly influenced the decrement in RT ($p>0.05$). The highest mean rating for body vibration was "Very Slight"; this occurred at 600 Hz. Loudness ratings increased linearly as SPL increased ($p<0.0001$) approaching a mean rating of 'Severe" at 166 dB. The 2420 Hz signal was perceived as significantly louder than the other frequencies ($p<0.01$).

CONCLUSIONS: Exposures to 600–2420 Hz WBS at SPLs up to 166 dB produce relatively low sensations of body vibration and result in small, but clinically insignificant, effects on a simple cognitive task. While recreational divers tolerate these sound exposures well, an increasing number of subjects give high loudness ratings (">Very Severe") once the SPL exceeds 154 dB.

INTRODUCTION

Most of the early research on the biophysical and psychological effects of low frequency waterborne sound (LFWBS) in humans has focused on frequencies below 500 Hz. The impetus for previous LFWBS studies was provided by the emergence of low-frequency active acoustics as a critical antisubmarine warfare technology (Tyler 1992). Specifically, the U.S. Navy was required to provide an environmental impact statement for the operational use of a newly developed towed sonar array system (SURTASS LFA) that operates at frequencies below 500 Hz. Due to the high powered nature of this system, and the long propagation distance of low frequency sound, there was a possibility that high levels of underwater sound may encroach on popular recreational dive sites.

At the time when the SURTASS LFA system became operational there was little information available in the scientific literature on the bioeffects of low frequency sound on divers. To determine safe exposure levels to low frequency underwater sound, human diving experiments were carried out in the 1990s by US Navy labs and a consortium of US universities as well as the Ministry of Defence in the United Kingdom. Table 1 summarizes the studies of low frequency underwater sound that have been conducted to date and is an update of the Table provided in Steevens et al., (1997). Many of the studies in Table 1 were conducted to provide data for the SURTASS LFA environmental impact statement which has been recently published by the Department of the United States Navy (2001). The SURTASS LFA environmental impact statement provides guidelines for peacetime use of military low frequency active sonar that operate within the 100-500 Hz frequency band.

Recent developments in sonar technology are exploring the use of new Low Frequency Active sonar systems that operate within the 500–2500 Hz frequency range. The higher frequency range of the new sonar offers advantages for detecting submarines in littoral waters. In anticipation of the operational use of these new sonar systems, the US Navy has continued to support research investigating the bioeffects of LFWBS on divers. This continuing research effort aims to provide information on which to formulate exposure limits for both military and civilian divers exposed to LFA sonar within the 500 – 2500 Hz frequency range.

The current report describes the third in a series of three experiments designed to evaluate the psychophysical effects of (LFWBS) in the 500-2500 Hz range on both US Navy and recreational divers. During the first two experiments, 31 U.S. Navy divers were exposed to LFWBS at 6 frequencies from 600 to 2500 Hz at Sound Pressure Levels (SPLs) up to 163 dB re. 1 μPa. The duration of the LFWBS was from 7 to 28 seconds. The primary objective of the first two experiments was to determine the relationship between aversion and sound pressure level (SPL) in U.S. Navy divers exposed to sonar exposures across the frequency range of interest. Other objectives included determining the influence of frequency, signal type, and inert gas narcosis on aversion to LFWBS and on the presence or absence of vibration sensations. Preliminary results have been reported in Fothergill et al., (2000, 2001a) and are included in Table 1.

The main findings from Fothergill et al., (2000) were that aversion to LFWBS and the probability of detecting vibration increased linearly with increasing SPL. The probability of detecting vibration was greatest at 600 Hz and the least at 2000 Hz. These frequencies also corresponded to most and least aversive frequencies, respectively. Across all frequency and signal conditions there was a 10% probability that an aversion rating would exceed "Very Severe" (seven on the category-ratio scale) at the highest SPL (163 dB). There was no significant difference in aversion among the three different signal types tested in this study.

The main conclusions from Fothergill et al., (2001a) were that at SPLs of 151 dB and above, aversion and perception of vibration to LFWBS is reduced under mild inert gas narcosis. In contrast to previous results at lower frequencies and intensities (Sims et al., 1999), increasing the signal duration of 600 Hz LFWBS from 7 to 28 s increased the level of diver aversion to underwater sound, slightly, but significantly.

It should be noted that in the studies by Fothergill et al. (2000, 2001a), several of the subjects were familiar with the effects of LFWBS, following their participation in similar previous experiments. Furthermore, the procedures used in Fothergill et al., (2000) used a sequential increase in SPL for a given frequency and signal type rather than random presentation. The subjects were also under full control of the sound exposures. These procedures were adopted to minimize the possibility of a subject de-volunteering as a result of aversion to the sound exposures. It was thought that these precautions would optimize the chances of obtaining usable data while at the same time enabling the main objective of the study to be met within the limited time and budget constraints.

Because of the extensive training and experience of the US Navy divers, as well as the conservative procedures described above, none of the divers aborted their dive or showed a panic reaction as a result of the sound exposures. Furthermore, there were no measurable deficits in cognitive performance or changes in hearing acuity due to the sound exposures. While the data from Fothergill et al., (2000, 2001a) provides useful information on the psychophysical responses of well-trained U.S. Navy divers to LFWBS, information is still needed on the responses of other less well-trained diver populations.

The aim of this research was therefore to resolve the major concerns associated with the response of the recreational diver, who by level of training, experience and fitness may be less prepared to successfully cope with an unexpected exposure to LFWBS. The primary focus of the present study was to determine the psychophysiological reactions of recreational divers presented with sound unexpectedly and to determine if such reactions place naive divers at risk of harming themselves. To achieve this goal, we used individuals who were not US Navy dive trained and had never been involved in an underwater sound experiment.

Table 1
Previous Studies on the Bioeffects of Low Frequency Underwater Sound

Author	Method	Frequencies	SPL	Time of Exposure
Nyborg 1993	Modeling	< 1000 Hz	< 160 dB	Minutes
Crum and Mao 1993	Modeling	< 1000 Hz	< 190 dB	Minutes
Suki et al. 1994	Modeling	250 Hz	Not specified	Minutes
Duykers and Percy 1978	Pig exp. (head out) (n = 4)	40-70 Hz	144-167.5 dB	1.5-18 minutes
Rogers et al. 1994	Human exp. (n = 5)	50-500 Hz	130 dB	4-6 sec. x 30
Verrillo et al. 1994	Human exp. (n = 6) + Modeling	250 Hz	< 180 dB	Minutes

Table 1 Con't

Author	Method	Frequencies	SPL	Time of Exposure
Smith et al. 1996	Human exp. (n = 27)	125, 250, 500,	161 dB 171 dB	4 minutes 4-15 minutes
		1000 Hz (± 5% warble)	181 dB	4-15 minutes
Steevens et al. 1994a	Human exp. Head out (n=22)	225-275 Hz (warble)	160 dB	5-10 min>(cont.) + 30-60 sec. x 5
Steevens et al. 1994b	Human exp. 33 fsw (n = 18)	160-320 Hz (warble)	160 dB	5 minutes
Steevens et al. 1999	Human exp. 60 fsw (n = 1)	160-320 Hz (warble)	160 dB	15 minutes
Russell and Knafelc 1995	Human exp. 33-133 fsw (n = 22)	160-320 Hz (warble) 160-260 Hz (sweep) 240-320 Hz (sweep)	160 dB	100 sec. pulses x 9 (50% duty cycle)

Table 1 Con't

Author	Method	Frequencies	SPL	Time of Exposure
Steevens et al. 1994b	Human exp. 30 & 60 fsw (n = 6)	160-320 Hz (warble) 240-320 Hz (sweep)	160 dB	100 sec. pulses x 9 (50% duty cycle)
Sims et al., 1999	Human exp. Depth 1 m (n=20)	100-500 Hz (pure tone)	120 dB	1 sec.
Fothergill et al., 2001b	Human exp. Depth 1 m (n=23)	100-500 Hz (pure tone, 30 Hz sweep up and down)	130-157 dB	Repeated 7 sec. signals
Sims et al., 1998b	Human exp. Depth 1 m (n=26)	100 Hz (pure tone, 30 Hz sweep up and down about center frequency)	136 dB	7, 14, 21, 28 sec. (50% duty cycle)
Sims and Fothergill 1999	Human exp. Depth 1 m (n=24)	100, 250, 500 Hz pure tone	126 –157 dB	Repeated 28 sec signals
Parvin et al., 1994	Human exp. 20 meters depth (n = 4)	15-1500 Hz	160 dB	5 min. sweeps x 3
Fothergill et al., 2000	Human exp. Depth 1 m (n=31)	600, 800, 1000, 1500 2000, 2500 Hz pure tones and 10% hyperbolic sweeps up and down	140 –163 dB	Repeated 7 sec signals
Fothergill et al., 2001a	Human exp. Depth 1 m (n=31)	600, Hz pure tones	140, 151 and 163 dB	7, 14, 21, 28 sec signals (50% duty cycle)

OBJECTIVES

i. Determine if LFWBS presentations at frequencies between 600 and 2500 Hz at SPLs up to 166 dB result in avoidance behavioral responses (i.e. ascents to the surface to avoid the sound) and/or a significant startle response to the sound. These data will be used to determine the potential for causing indirect harm to a diver unexpectedly caught in a sound field. The data will predictions of panic in divers to be made.

ii. Determine if LFWBS presentations at frequencies between 600 and 2500 Hz result in cognitive diversion in recreational divers. Although some subjects may not show avoidance behavior to LFWBS, there may be some degree of diversion from a task because of the sound exposure that may interfere with diving procedures, underwater work or overall dive safety.

iii. Determine if the magnitude of a startle response to LFWBS is related to the individuals state or trait anxiety level.

iv. Determine psychophysical perceptions of loudness and vibration to LFWBS as a function of SPL and frequency.

<u>Hypotheses Tested</u>

i. Divers with the highest state and trait anxiety will be those most likely to show avoidance behavioral responses in response to high levels of LFWBS.

ii. LFWBS will divert a diver’s attention and reduce their performance (increase reaction time (RT)) on a two choice RT test. The increase in RT will be independent of the sound pressure level and frequency of the sonar stimulus.

iii. LFWBS stimuli of 154 dB and above will result in a physiological startle response (i.e., a temporary cardiac acceleration). The rationale for this hypothesis is based upon preliminary results from NSMRL protocol 30358 that indicate the emergence of a temporary cardiac acceleration during sound presentation at 151 dB that was more clearly defined at 163 dB.

iv. Vibration ratings will be highest for the lowest frequencies tested, and will increase in direct proportion to the sound pressure level.

METHODS

<u>Subjects</u>

Active duty military and Coast Guard personnel were recruited as subjects by advertising in the Naval Submarine Base New London paper (The Dolphin) and in local dive shops and dive clubs. Flyers requesting subjects for the study were also placed around the Submarine Base, New London and at the Coast Guard academy in New London. An electronic message was also sent to various commands on the Submarine Base, New London, Coast Guard Academy and other local Coast Guard Commands for inclusion in their plan of the day (see Appendix A).

Subjects were required to be at least 18 years of age and hold a recognized civilian diving certification. (e.g. Professional Association of Diving Instructors [PADI]; National Association of Underwater Instructors [NAUI]; Young Men's Christian Association [YMCA] etc.). Medical fitness for diving was screened by history (review of the Coast Guard or military medical record and the Medical Data Form shown in Appendix B) and physical examination by a U.S. Navy diving medical officer. Any subject with an absolute contraindication for diving as outlined by the Recreational SCUBA Training Council's (RSTC) guidelines for physicians (see Appendix C) was disqualified from participating in this study for safety reasons. Qualified Navy divers as defined in OPNAVINST 3150.27A were excluded from participating because of their extensive dive training and the fact that the goal of this study was to evaluate the responses of recreational divers only. To comply with the U.S. Navy diving directive OPNAVINST 3150.27A a general waiver on physical standards for civilian-trained military divers was obtained from Naval Military Personnel Command (CHNAVPERS) (with Bureau of Medicine and Surgery concurrence). There were no exclusion criteria for high frequency hearing loss, which is common in the diving community.

Nineteen male and two female active duty military recreational divers participated in the study. The subject population had a mean age of 29 years, (range 20 - 52 years). The average number of years diving was 5.7 years (range 0 - 16 years) with a mean number of dives since certification of 95 (range 0 – 500).

Testing Location

All dive experiments were conducted at the Dodge Pond Acoustic Measurement Facility, Naval Undersea Warfare Center Detachment (NUWC), Niantic, CT (see Figure 1). This site was chosen as the testing site for the following reasons:

- The test site is secure and under U.S. Navy control (no gasoline-powered motor boats are allowed on the pond).
- The pond's depth, sloping sides, and mud bottom reduce the influence of sound reflections (echoes) on the acoustic test field. When compared to a pool, the pond more accurately simulates the open water conditions, where a diver may be exposed to LFWBS.
- NUWC's barge facilities allow for optimal adjustment of the sound transducers and diver placement to achieve a consistent sound field at the diver's location.
- The pond has a very low level of background sound across all test frequencies. For most frequencies the ambient noise levels in Dodge Pond are well below Sea State 0 (see Figure 2).
- All rigging and electronic support is protected from the weather, allowing experiments to be conducted throughout all seasons.
- Navy diving support and local hyperbaric chambers are available. Dodge Pond is a 20-minute drive from the Naval Submarine Medical Research Laboratory (NSMRL) hyperbaric chambers, the Naval Ambulatory Care Center Groton and several civilian hospitals.
- The site was available for use during the time frame proposed for the current study.

Figure 1. The Naval Underwater Warfare Center Acoustic Test Facility, Dodge Pond, Niantic, CT.

Diving Set-up

All dives were performed within a large, five-sided, open-top, plastic, hard-walled tank (1.25m wide x 2.25m long x 3.5m deep), suspended beneath the command control platform of the barge at Dodge Pond (see Figure 3). The tank is acoustically transparent at the frequencies tested. Heated water was supplied to the tank to maintain the water temperature at a comfortable level for the diver during the dives. All divers wore a fully deflated buoyancy compensator, a standardized SCUBA face mask and a full 3-mm neoprene wet suit (without hoods or gloves). Divers were negatively buoyant and suspended in the tank in a prone position at 1-m depth using support lines to the legs and upper body. Compressed air was supplied to the divers via a standard SCUBA regulator (US Divers) attached via a long second stage hose to SCUBA cylinders at the surface (i.e. a hooka rig).

All dives were performed in accordance with the U.S. Navy Diving Manual Revision 4, 1999. Each subject had a tender/safety monitor at the surface that tended a safety line attached to a diver worn harness. The tender's role was to assist the diver in case of emergency. In addition

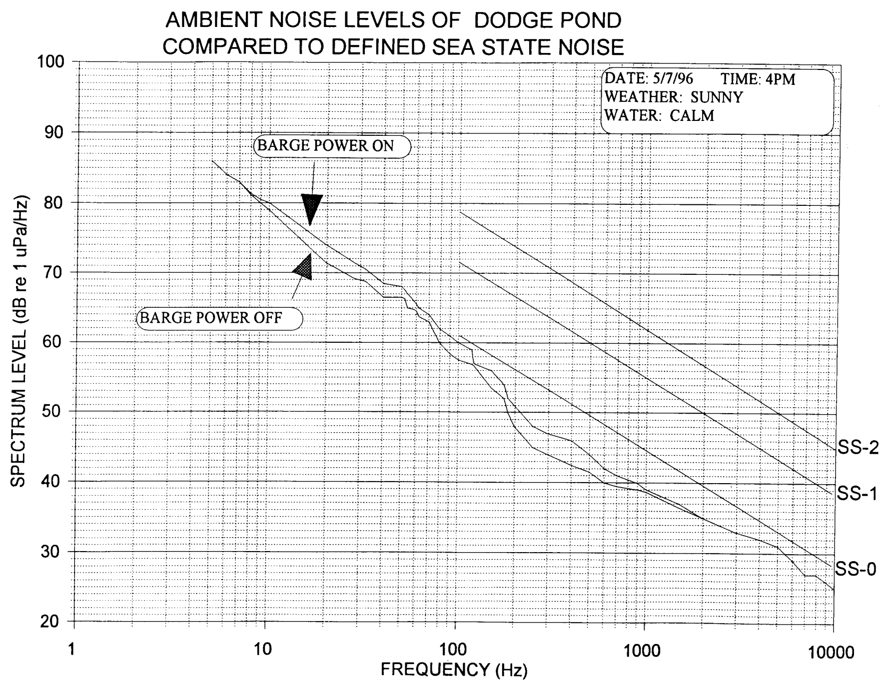

Figure 2. Ambient subsurface noise levels in Dodge Pond. SS = Sea State.

to the tender, a safety diver was also present. Communication from topside to the diver was facilitated by an in-water communication diver recall system. Divers communicated with topside using an underwater control console (see below) and line-pull signals.

Sound Mapping and Acoustic Set-up

Two sound sources were used to cover the frequency range for the current experiment. An HX-188 sound projector was used for frequencies up to and including 1750 Hz and a TR-317 sound projector was used for frequencies above 1750 Hz. Both sound projectors were placed at a depth of 0.8 m outside of the Lexan™ box and in line with the head and torso of the diver. The source placement was designed to make the sound field at the diver axis in the region of head and thorax as uniform as possible. A diagram of the transducer set up is shown in Figure 4. Prior to human testing, the sound field in the region of the diver was mapped with the diver absent using an array of 5 hydrophones spaced along an axis at 0.25 m intervals. The hydrophone array was oriented along the head to foot axis of the diver position and subsequently moved to 5 positions perpendicular to its length to measure the uniformity of the sound field in a volume around the diver. The 5 positions of the array are shown in Figure 4 and are listed below.

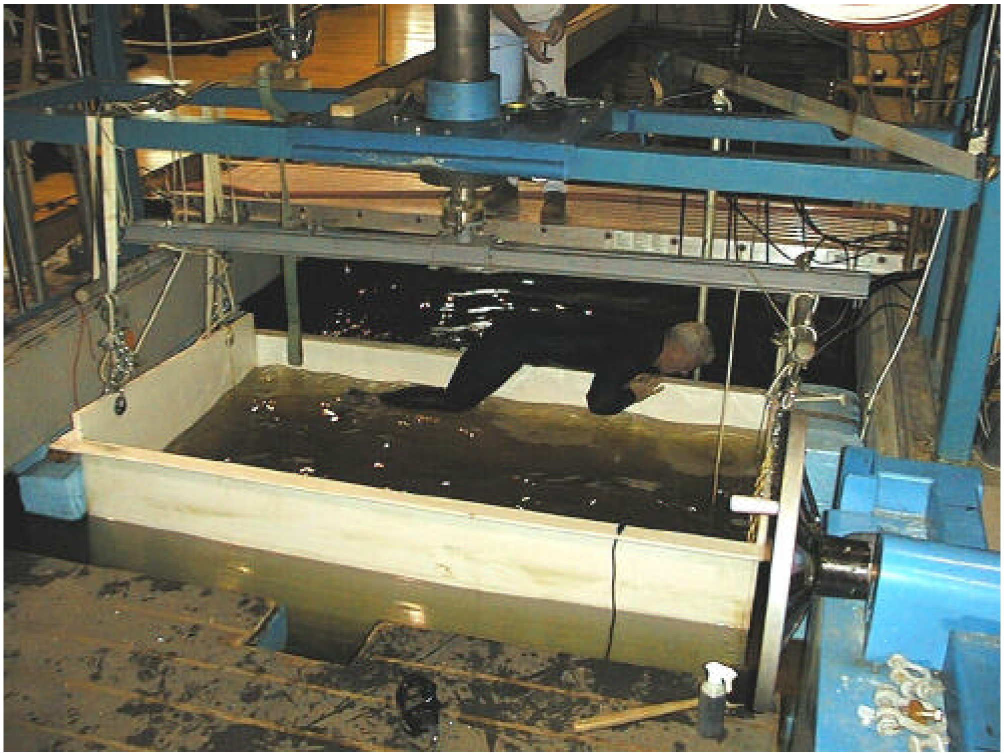

Figure 3: (Left) The plastic acoustically transparent box placed within the well of the barge at Dodge Pond. All diving was performed at 1 m depth within this box. The underwater sound transducers were placed outside the box at a depth of 0.8 m (see Figure 4 below).

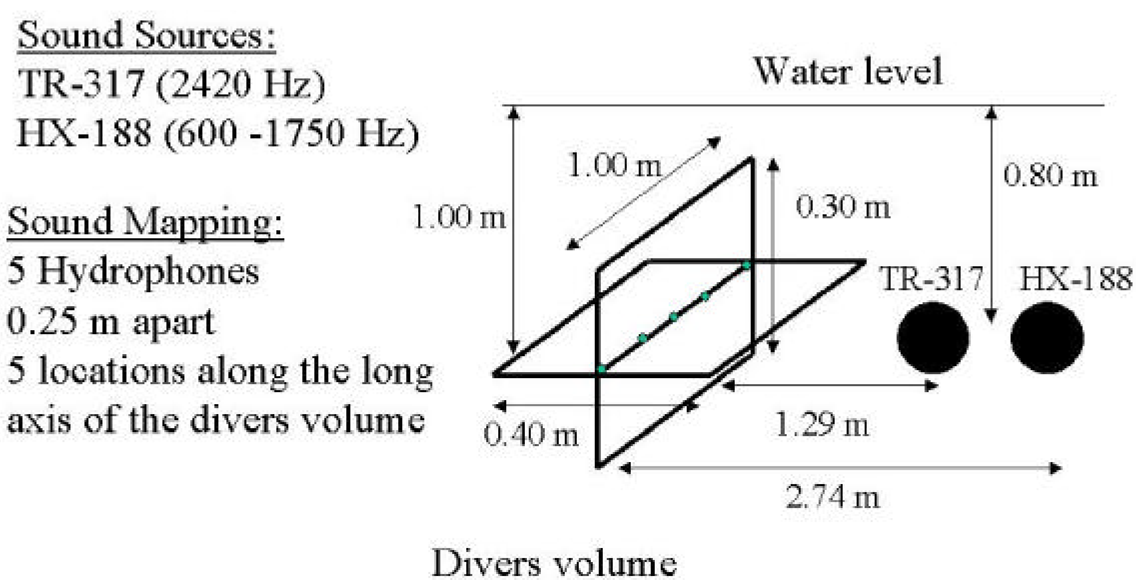

Figure 4. Underwater transducer set-up and sound mapping of the diver's volume (test space).

Positions used for the hydrophone array during sound mapping of the diver's volume.

1. Center (along the diver axis at a depth of 1 m).
2. Down (0.15 m down from the diver axis).
3. Up (0.15 m up from the diver axis).
4. Away (0.20 m away from the source at the depth of the diver).
5. Toward (0.20 m toward the source at the depth of the diver).

The initial pure tone test frequencies chosen for the study were 600, 1000, 1750 and 2500 Hz. However, after preliminary sound mapping measurements were made it was found that large deviations in the sound field occurred for the 2500 Hz tone. A more uniform sound field was obtained when the frequency was lowered to 2420 Hz. Consequently, it was decided to change the highest frequency tested from 2500 Hz to 2420 Hz. Results of the sound mapping for 600 Hz through 2420 Hz are shown in Appendix D.

A schematic of the equipment set-up, used during the experiments, is shown in Figure 5. Sound generation, acoustic monitoring and data acquisition were controlled by two IBM clone computers. A master computer contained the primary program, written in Lab View, that controlled the RT task and presented, stored and collected the diver's responses transmitted from the diver response box. The master computer also controlled a second slave computer which provided signals to the two underwater sound projectors via their respective filters and amplifiers to generate the underwater pure tones.

Underwater Sound Exposures

All LFWBS stimuli were 28-second pure tone signals with a rise and fall time of 20 ms. The frequencies and Sound Pressure Levels (SPLs) of the signals are shown in Table 2. At each of the four test frequencies, 4 SPLs between 140 and 166 dB were presented. Each subject therefore received 16 distinct LFWBS exposures (4 SPLs x 4 frequencies); each of which was presented twice for a total cumulative sound exposure of 14.9 min (i.e. 28-second pulse duration x 4 frequencies x 4 SPLs x 2 presentations). The SPL for the 600 Hz was limited to 163 dB, due to initial concern over possible vibratory effects at this frequency with higher SPLs.

The order of stimulus presentation was predetermined using a computer which randomly ordered the 16 LFWBS stimuli together with three silence periods. The randomly generated stimulus order matrix is shown in Appendix E and was programmed into the software that provided the sound presentations during the experiments. The silence periods were used as control (or sham) trials, in which the subjects performed the RT test without the presence of LFWBS. A second computer-generated list randomly selected where, within the stimulus order matrix, a given subject began their sound exposures (i.e., which sound exposure was first). The conditions for the second list were that, (i) the subject would not start with a sham trial and (ii) at least 1 subject would be represented in each one of the starting positions. Once the starting position (initial sound exposure) had been chosen and entered into the computer, there was a choice to go forward or backward through the stimulus order matrix. During the experiments, the direction in which the subjects conducted the stimulus order was counter balanced. Since each subject ran through the stimulus order matrix twice during the dive, there were six sham exposures for comparison with the LFWBS sound exposures.

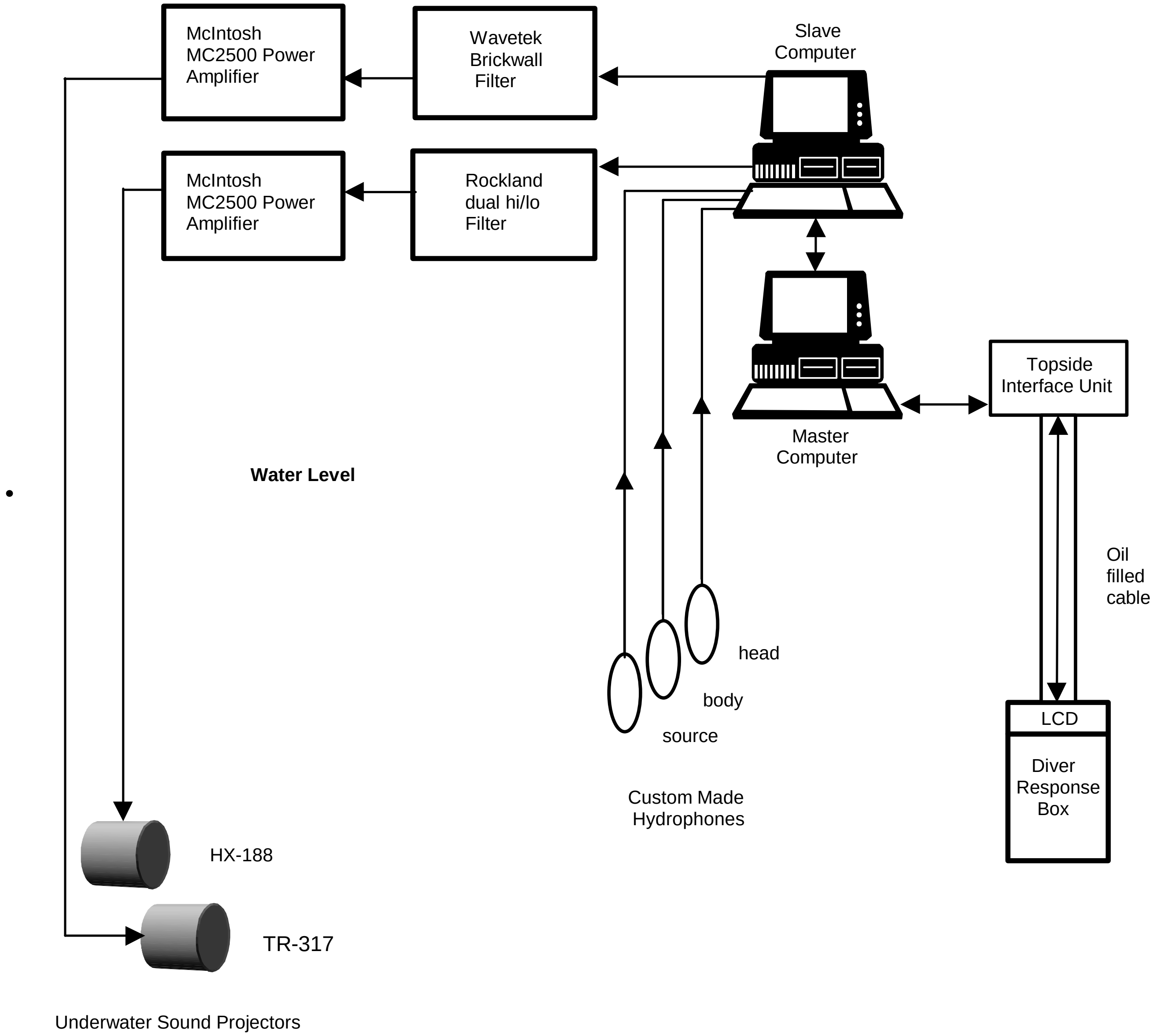

Figure 5. Schematic of the equipment set-up.

Table 2. SPLs tested at each frequency

Each Frequency SPL combination was tested twice per subject				
Frequency				
600 Hz	140 dB	148 dB	154 dB	163 dB
1000 Hz	140 dB	148 dB	154 dB	166 dB
1750 Hz	140 dB	148 dB	154 dB	166 dB
2420 Hz	140 dB	148 dB	154 dB	166 dB

<u>Pre- and Post-Dive Testing</u>

On the morning of the dive, a standard in-air audiogram was measured for each subject at the NSMRL. The audiogram was conducted within a sound-proof booth (Controlled Acoustical Environments, Industrial Acoustics Comp. Inc., NY) by a qualified auditory technician or audiologist using a calibrated GSI 16 Audiometer (Model 1716, Grason Stadler, MA). Subjects repeated the audiogram on the morning following their dive, to determine if there was any change in their hearing due to the underwater sound exposures. Statistical analysis of the data was conducted using a repeated measures analysis of variance (ANOVA) with test day (pre versus post dive audiogram), frequency (6 levels from 500 Hz to 6000 Hz), and ear (left or right) as independent variables. Significance was set at the 0.05 level.

After arriving at the dive site, subjects completed the State-Trait Anxiety Inventory (STAI) for Adults (Spielberger 1983). Data from this test was used to assess the subject's pre dive anxiety level and to assess if our subject population's Trait anxiety level varied substantially from the general military population. Subjects then performed the automated Neuropsychological Assessment Metrics (ANAM 2000) test battery to assess their cognitive and memory function (Reeves et al., 1998).

The ANAM 2000 test battery is a computer based clinical subset of the Office of Military Performance Assessment Technologies, Testers work bench that was derived using components from the United Tri-service Cognitive Assessment Battery (Englund et al., 1987) and the Walter Reed Performance Assessment Battery. The ANAM 2000 is purported to measure mental efficiency as well as accuracy for a variety of cognitive tasks. Details of the sub-tests and their purported measures are discussed in detail in Reeves et al., (1998). The nine sub-tests chosen for the current experiment are listed in their order of presentation below.

Sub-tests used in the ANAM 2000 test battery

1. Demographics form
2. Stanford Sleepiness Scale – Measures alertness level
3. Simple Reaction time – Measures basic psychomotor speed
4. Code Substitution (Letter/Symbol Comparison) – Measures visual scanning and learning
5. and 9 Code Substitution (Short and Long-Delay) – Measures immediate and delayed recall
6. Matching to Sample – Measures pattern recognition, visual scanning, attention, working/short term memory and decision making
7. Running Memory Continuous Performance Task (CPT) – Measures working memory

8. Mathematical Processing Task – Measures computational speed and working memory.

Each subject was guided through the computer instructions for each task to ensure they understood how to perform the sub-task correctly. After showing satisfactory performance on each of the tasks, they then completed the full test battery a total of three times, to assist in stabalizing performance. A fourth test battery was conducted by each subject within 30 minutes of completing his or her dive. Data from the third trial was compared with post dive performance to determine if there had been a change in cognitive function because of the subject's participation in the study.

Performance on sub-tasks 3 through 8 was characterized by the mean reaction time (MRT), percent accuracy of response (ACC), and throughput (TTP, the number of correct responses per minute). Preliminary analysis of these data was conducted using paired t-tests to assess differences in scores between pre and post dive. Because of the large number of comparisons performed, the significance level of the paired t-test was set at 0.01 level, to reduce the chances of committing a Type I error. In addition, a more powerful split plot repeated measures analysis was performed on the MRT data for sub-tasks 3 through 8, to determine if participation in the diving experiments resulted in a significant general effect on RT.

Experimental Protocol

As the primary goal of the study was to understand how a diver reacts to a sound that he/she is not expecting, it was important that the subject remain blinded from the true objective of the experiment until after the exposures. If the subject were to be informed that the objective of the experiment was to investigate startle responses to LFWBS, they may form a cognitive preparatory strategy that would reduce the chance of observing a true startle response. In an attempt to minimize this preparatory strategy, subjects were instructed that the primary objective of the study was to determine how well they could perform a RT task underwater, during the presence of underwater sound. Although subjects were informed of the risks associated with LFWBS and that LFWBS may or may not be present during the RT task, they were not forewarned when the stimulus would be presented.

The Committee for Protection of Human Subjects at the Naval Submarine Medical Research Laboratory, Groton, Connecticut and Naval Health Research Center, San Diego, CA approved the study. Final approval was obtained from the Bureau of Medicine and Surgery, Washington, D.C. After being briefed on the study, all subjects signed informed consent forms. In addition, all female subjects underwent a pregnancy test on the morning before their dive to ensure that they were not pregnant immediately prior to their participation in the study.

Following completion of pre-dive testing (see above), subjects were instrumented with a three-lead electrocardiogram designed for underwater use. They then donned a 3-mm neoprene wet suit and were trained topside on how to operate the underwater diver response console shown in Figure 6. Topside training included: (i) practice on the underwater RT task (see below), (ii) instructions for rating loudness and vibration, and (iii) procedures for aborting a dive.

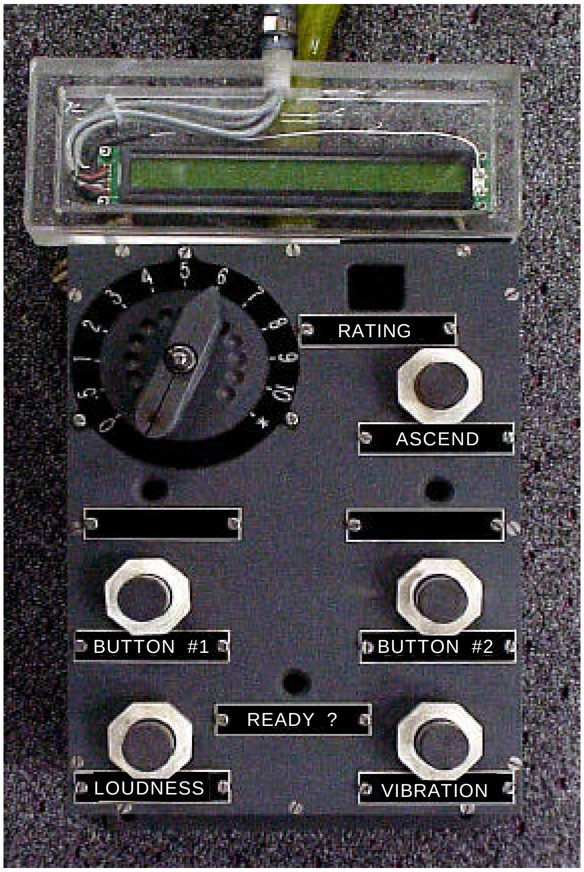

Figure 6. The underwater diver response box and liquid crystal display (LCD) used during the experiments. Divers were instructed via the back lit LCD when the reaction time (RT) test was about to commence and when to rate loudness and vibration (see text for further details). The RT and psychophysical data were relayed to the surface via an oil filled cable to a purpose built top side interface unit, before being passed to a computer for storage and analysis (see Figure 5).

Underwater Reaction Time Task

The underwater RT task was a simple two-choice visual RT task that was performed using the underwater console shown in Figure 6. At the start of the test, the ready light on the underwater console illuminated to warn the subject that the RT test was about to begin. Several seconds later light #1 or light #2 was illuminated on the underwater console for 500 ms. The subject was instructed to respond to the light stimulus by pressing either button #1 or #2 as quickly as possible. When light #1 was illuminated, the subject responded by pushing button #2. When light #2 was illuminated, button #1 was pressed. A timer measured the subject's RT from the onset of the light stimulus to when either button #1 or #2 was pushed. Measures of both speed (RT) and accuracy were recorded for repeated stimulus presentations. Reaction times faster than 200 ms or slower than 2 s were recorded as errors. The time interval from when the subject responded to when the next stimulus was presented varied randomly between 1 and 3 s.

During the topside practice session, the subject performed 65 trials. Once the diver was in place (suspended at 1 m in a prone position) and ready to begin the study, they performed an additional 65 trials, before being exposed to LFWBS. Within 10 – 15 seconds of completing the in-water baseline, subjects recommenced the RT task. At a random time between the 4th and the 8th RT trial, the diver was exposed to LFWBS. The subject attempted to maintain his/her attention on the RT time task for a further 9 RT trials while being exposed to the LFWBS. After completing these 9 RT trials they were cued by light #3 to use the Borg scale to rate their loudness perception and sensation of vibration during the sound exposure (Borg 1982). Each

LFWBS exposure lasted 28 seconds and was followed by a rest interval (silence period) of no less than 28 s. After the rest interval subjects were instructed to begin the RT task again, and the above procedures were repeated until all the sound presentations were completed.

For each subject and for each SPL-frequency combination, a mean RT was calculated from the trials immediately prior to the onset of the LFWBS and a second mean RT from the trials during the LFWBS exposure. As subjects occasionally missed the first pre-sound RT trial, this trial was omitted from the calculation of the pre-sound RT mean. The percent change in RT was then calculated from the difference between the pre-sound exposure and exposure RTs. This percent change in RT was subjected to a two-way repeated measures analysis with frequency (4 levels) and SPL (4 levels) as independent variables. For the purpose of this analysis, the highest SPL level at each frequency was considered equivalent.

A mean percent change in RT was also calculated from the six sham trials in similar fashion to that described above. In this case, the computer picked a random time between the 4th and the 8th RT at which to begin the sham period. RT times collected prior to this point were considered pre–sham trials and those after this point were during the sham trial. A separate paired t-test was conducted to compare the percent change in RT during the sham trials with the average change in RT recorded during the LFWBS exposures. The number of choice errors (pressing the wrong button) was also recorded for the first exposure at each sound pressure level (i.e. sham, 140, 148 ,154 and 163 or 166 dB). Changes in the frequency of choice errors between the sham trail and the LFWBS exposures were analyzed using the Chi-square test. Significance for all tests were set at alpha = 0.05.

Subjective Ratings

Subjective perceptions of loudness and vibration to LFWBS were rated using the Borg Category-ratio scale (Borg 1982) shown below. The descriptors were placed directly in front of the diver on a waterproof placard.

Rating	**Descriptor**
0	None at All
0.5	Extremely Slight (just noticeable)
1	Very Slight
2	Slight
3	Moderate
4	Somewhat Severe
5	Severe
6	
7	Very Severe
8	
9	
10	Extremely Severe (almost max.)
*	Maximal

The diver used the dial on the underwater console to rate the perceived loudness of the sound and level of vibration felt. A rating of “0” indicated that no sound was heard or no vibration was felt. A rating of “10” was defined as that stimulus intensity which results in the subject wanting to immediately terminate an open ocean dive because of the loudness or level of vibration during the sound exposure. The * or Maximal rating allows the scale to remain open ended so that the subject could rate an exposure higher than a 10 if a 10 had already been rated for a previous stimulus. If a diver gave a maximal response they were asked to rate the sound presentation with a number greater than 10. They were then asked if they wanted to continue with the experiment. All ratings given by the subject were automatically recorded in a computer data file once the subjects pressed the “Enter” button on the underwater console.

Statistical analyses of the loudness and vibration ratings were conducted using three-way repeated measures analysis of variance with first versus second presentation, frequency, and SPL as the independent variables. As the highest SPL was different for the different frequencies, two separate analyses were performed. The first repeated measures ANOVA analysis included all the SPLs (140, 148, 154 dB and highest SPL) and the second analysis included only the first 3 SPLs (i.e. 140, 148 and 154 dB). Post Hoc analysis was conducted using Tukey’s Honest Significant Difference. Significance was set for all tests at alpha = 0.05.

Procedure for aborting a dive

The diver was instructed to use the ASCEND button if they wanted to leave the sound field. Although the divers were only 3 feet below the surface, they were instructed to pretend that they were 15 feet below the water. If they could not tolerate the LFWBS, they were instructed that they could ascend to the surface to avoid the sound. However, any ascent to the surface must be done at a “safe rate”, i.e. a rate not to exceed 30 feet/min. Thus it should take the diver 30 s to reach the surface from a pretend depth of 15 feet. To simulate a 30 s “safe” ascent, the diver was instructed to push and **hold down** the ASCEND button while a timer counted down 30 seconds. Since the duration of the sound was only 28 s and the ascent period was 30 s, a diver pressing the ASCEND button immediately on sound presentation may remain submerged if they perform a “safe ascent” since the sound would terminate prior to ascent. Release of the button terminated the sound immediately at any time during the count down. Thus, divers deciding that they could not tolerate the sound during a 30 s “safe ascent period” had to release the button to come to the surface immediately, thereby terminating the sound exposure.

Any use of the ASCEND button terminated the RT test for that trial. Ascent to the surface to avoid the sound was defined accordingly: 1) “Panic” - immediate ascent to the surface (failure to push the ASCEND button), 2) “Potentially harmful ascent” -ascent faster than 30 s, 3) “Aborted dive” - any ascent to the surface at the appropriate rate. Any use of the ASCEND button that resulted in a “potentially harmful ascent” or “panic” eliminated further presentations for that subject for that frequency and SPL as well as further increases in SPL for that frequency. If subjects ascended to the surface for any reason they were asked if they desired to continue with the dive.

Heart Rate and breathing frequency

Heart rate (HR) was monitored continuously during each test, using a three-lead electrocardiogram designed for underwater use. The EKG signal was digitized at a sample rate of 1000 Hz, using AcqKnowledge® III hardware (BIOPAC Systems Inc, Santa Barbara, CA), before being presented online on an IBM laptop and stored on hard disk for later analysis. Beat-to-beat intervals were determined from the peak of one R wave to the peak of the next (R-R interval) using AcqKnowledge® III software. For each sound exposure or sham trial, the R-R intervals were divided into four periods, each containing five R-R intervals. The four time periods were: pre-sound exposure, early sound exposure (first five R-R intervals during the sound exposure), late sound exposure (next five R-R intervals during the sound exposure), and post sound exposure. The data analyzed for each subject were: the first sham trial, the first 140 dB exposure, and the first sound exposure greater than 154 dB. Statistical analysis was conducted using a repeated measures ANOVA, with the independent variables being SPL (3 levels), time period (4 levels), and R-R interval (5 levels).

In addition to HR, breathing gas temperature was monitored continuously using a fast response temperature probe (TSD102A thermister, BIOPAC Systems Inc, Santa Barbara, CA), placed in the mouthpiece of the SCUBA regulator. The temperature probe was interfaced to the same data acquisition system as described above. Fluctuations in gas temperature between inhalation and exhalation allowed respiratory frequency (f_b) to be monitored throughout the dive. Output from a monitoring hydrophone was also digitized and passed through the BIOPAC data acquisition system for synchronization of the sound stimuli with breathing pattern and heart rate responses.

For the purpose of analysis, breathing rates (f_b)were determined for approximately 28 s prior to and during the sound exposures for: (1) the first and last sound, (2) the first 140 dB exposure, (3) the first LFWBS exposure >154 dB, and (4) the first sham exposure. A one-way repeated measures ANOVA was performed on the respiratory frequency data to determine if there were any change in breathing rate between the sham exposures and the highest and lowest intensity sound exposures. In addition, a separate 2-way repeated measures ANOVA was performed on the respiratory frequencies prior to and during the first and last sound exposure to determine if: (a) breathing rate changed over the course of the experiment, and (b) whether f_b was affected by the sound exposures.

RESULTS

Pre- and post-dive testing

Statistical analysis of the audiogram data showed no significant changes in hearing acuity between the pre and post dive tests ($p>0.05$). The group mean ± SD State and Trait Anxiety Scores were 28 ± 5.8, and 28 ± 5.6, respectively. These values fall within the 10^{th} and 16^{th} percentile scores for male military recruits for State and Trait Anxiety, respectively (Spielberger, 1983). When compared with a group of qualified US Navy divers of similar age who took part in a similar previous experiment, both State and Trait scores were significantly higher for the recreational diver group ($p<0.05$).

Summary statistics showing the results of performance on the ANAM 2000 neuropsychological test battery are provided in Appendix G. Preliminary statistical analysis showed that the only significant changes between pre- and post-testing occurred for the code substitution, matching to sample, and math test. All the other tests showed no significant change in RT, accuracy or throughput (all $p>0.01$). The code substitution test showed evidence of a slight improvement in accuracy, from 94% to 96% post dive ($p<0.01$), while the math test showed a slight improvement in RT from 2255 to 2117 ms post dive ($p<0.01$).

The only performance measure showing a decrement post-dive was RT on the matching to sample test, which increased from a mean of 1174 ms to 1372 ms post dive ($p<0.01$). When the RT data from all the tests on the ANAM 2000 were subjected to analysis of variance, the overall main F statistic comparing pre versus post RT was not significant ($F_{1,20} = 2.82$, $p = 0.11$). However, there was a significant interaction between pre- versus post-RT and the sub-tests on the test battery ($F_{6,120} = 6.25$, $p<0.0001$). Tukey's post hoc analysis revealed that the significant interaction was predominantly the result of the slight increase in the mean post-dive RT on the matching to sample test described above.

Underwater Reaction Time

During the sound exposures, RT on the underwater task was 3.34% (SD ± 4 .99%) slower than during the period immediately prior to the onset of the sound. This was significantly different from the RTs during the sham exposures ($p<0.05$), which, as expected, changed little (mean % change = 0.36%, SD ± 7.29%) between the pre sham trials and the designated sham trials. Although the presence of LFWBS resulted in a 3% slowing of the underwater RT, ANOVA showed that this slowing was independent of the SPL ($F_{3,60} = 0.97$, $p=0.41$) and frequency ($F_{3,60} = 1.94$, $p=0.13$) of the waterborne sound. Analysis of the choice errors (pressing the wrong button) showed 3 subjects exhibiting choice errors during the first loud sound (163 or 166 dB), no subjects with choice errors during the first 140, 148 and 154 dB LFWBS exposure and two subjects with choice errors during the first sham exposure. The total number of choice errors was; 12 during the first loudest sound, and 2 during the sham exposure. Chi-square analysis of these frequencies showed a significant increase in the number of choice errors during the first loud sound compared with the first sham trial ($p<0.05$), but no significant difference in error rate between the first sham trial and the first 140, 148 and 154 dB exposure ($p>0.05$).

Subjective ratings

Loudness

None of the subjects aborted the dive due to the sound exposures or pressed the abort button on the diver response box. However, seven subjects reported that they were startled by some of the underwater sounds. Three subjects provided loudness ratings of 9 or greater during one or more of the sound exposures. All the high ratings were for sounds at the highest SPL and showed no particular bias towards any one frequency (600 Hz, n=2; 1000 Hz, n= 3; 1750 Hz, n=1; 2420 Hz, n=3). Based on these responses approximately 15% of divers would consider immediately aborting an open ocean dive if they were exposed to 28 seconds of LFWBS at these frequencies at SPLs between 163 and 166 dB. None of the divers gave ratings to indicate that they would abort a dive at 154 dB or less.

Statistical analysis of the loudness ratings showed that the ratings were dependent on frequency ($F_{3,42} = 6.41$, $p<0.01$) and SPL ($F_{3,42} = 89.86$, $p<0.0001$), but were similar for the initial and repeat exposures ($F_{1,14} = 0.08$, $p=0.79$). A repeat of this analysis with the highest SPL omitted from each frequency provided similar results. Figure 7 shows the change in loudness ratings with SPL for each frequency. As expected, the loudness ratings increase linearly with the increase in SPL, with differences between each loudness level being significant ($p<0.001$). Tukey's Post hoc analysis of the main effect for frequency revealed that the 2420 Hz tone was perceived louder than all the other frequencies (all comparisons with 2420 Hz $p<0.01$). Since Figure 7 does not give an indication of the wide inter-subject variability in the loudness ratings, Figure 8 is included to show the median and 95^{th} percentile confidence limits for the loudness ratings at each SPL tested. This latter Figure shows that 95 percent of recreational divers would rate the loudness of LFWBS at SPLs up to and including 154 dB as no more than Severe for frequencies between 600 and 2420 Hz.

The correlations between the mean loudness rating and State and Trait anxiety scores were low and non-significant (State anxiety, $r = 0.16$; Trait anxiety, $r = 0.22$).

Vibration

During the post-dive debriefing, six divers reported feeling vibration between the wet suit and skin and a further five divers reported feeling vibration in the region of the head, ears or sinus, during some of the sound exposures. Statistical analysis of the vibration ratings for SPLs up to and including 154 dB showed that the sensations of vibration during the LFWBS exposures were dependent upon SPL ($F_{2,40} = 6.24$, $p<0.005$), but independent of the frequency of the sound ($F_{3,60} = 1.38$, $p=0.26$). However, when the highest SPL was included in the repeated measures analysis of variance significant main effects were obtained for SPL ($F_{3,60} = 5.68$, $p<0.005$), frequency ($F_{3,60} = 3.90$, $p<0.05$) and the SPL x frequency interaction ($F_{9,180} = 2.27$, $p<0.05$). The different conclusions arising from these two analyses are best explained graphically as shown in Figure 9. The first point to notice from Figure 9 is that the mean ratings for vibration sensation are very low even at the highest SPL tested. Secondly, for the data points up to and including 154 dB there is little difference in the vibration ratings reported for the different frequencies or for the different SPLs. However, when least squares linear regression lines are fitted for each frequency using all the data points, the interaction is clearly evident from the steeper slope for the 600 Hz frequency compared to the other frequencies.

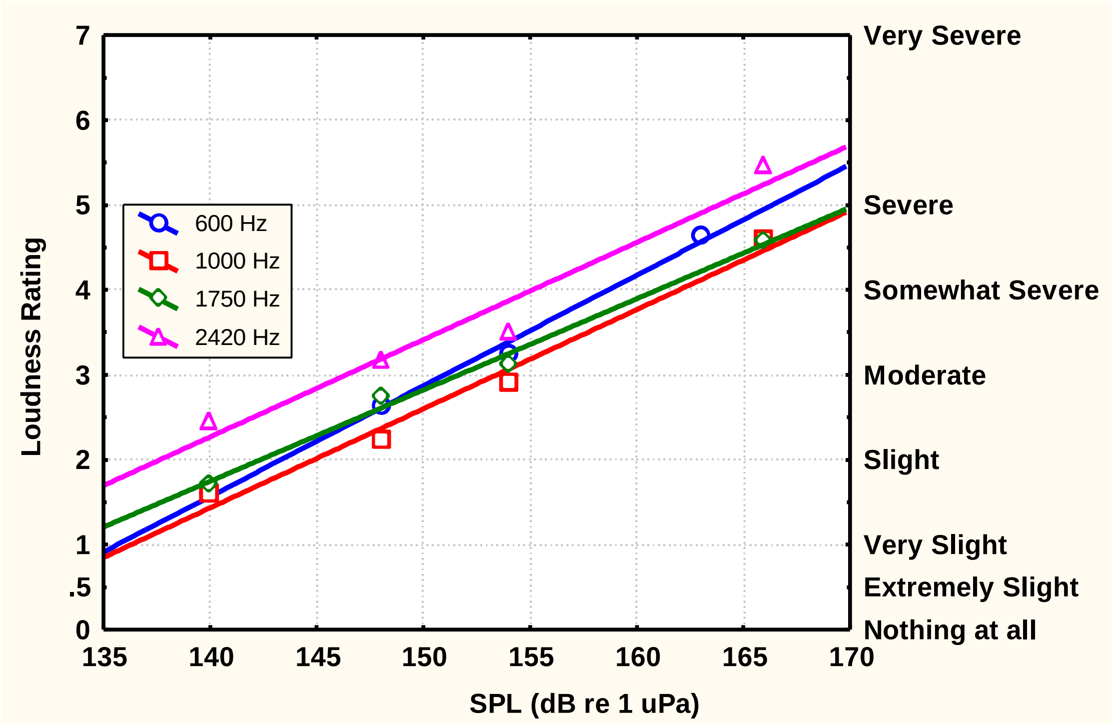

Figure 7. Loudness ratings by frequency for the LFWBS exposures. The data are means from 21 recreational divers. The lines through the data points were fitted using least squares linear regression. See Appendix F for the regression equations.

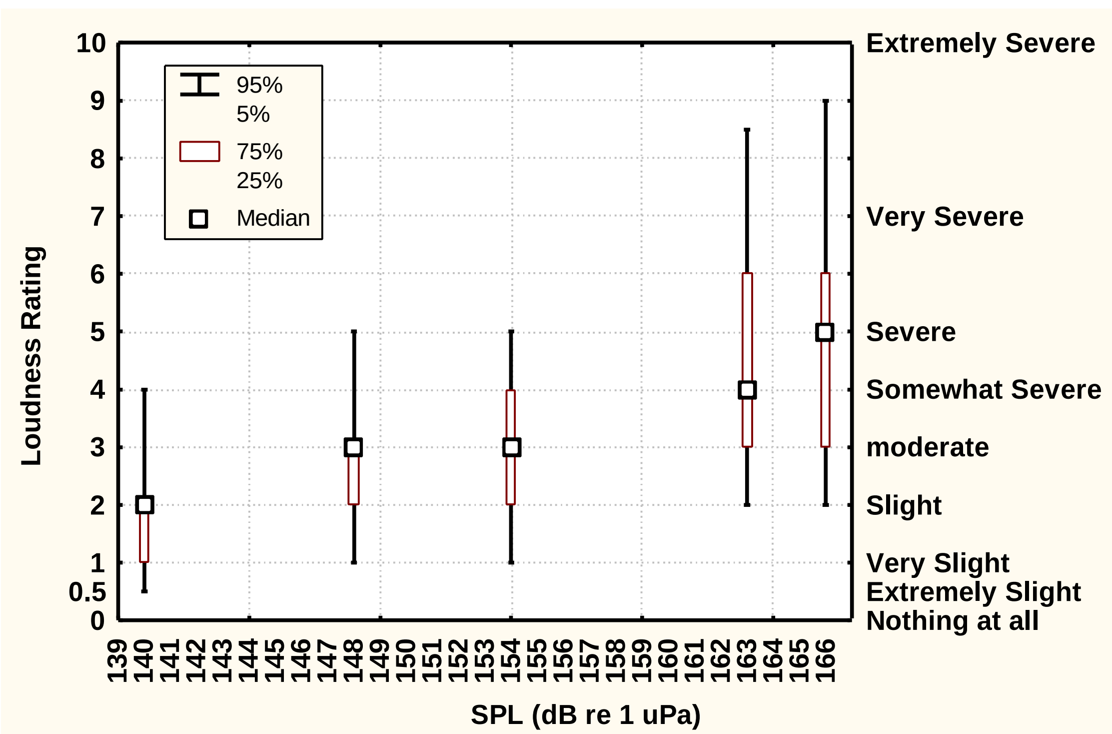

Figure 8. Median and percentile loudness ratings at each SPL for the LFWBS exposures. Data includes all frequencies and are for 21 recreational divers.

Variability of the vibration ratings is shown for each SPL in Figure 10. Over most of the SPL range, there was little variability with 95% of the ratings falling below 2 ("Slight") for SPLs of 154 dB and below. The largest variability occurred for 600 Hz at 163 dB. However, even for this data point 75% of the ratings given for vibration were "Very Slight" or lower. There were no vibration ratings greater than Severe for any of the sound exposures.

Heart Rate and Breathing Frequency

All heart rate data were analyzed and presented in the beat domain. Results showing the group mean changes in the R-R intervals for the sham exposures, and the first low (140 dB) and high (163 – 166 dB) SPL exposures are shown in Figure 11. Statistical analyses of these data showed that there were no significant differences in heart rate between these three conditions ($F_{2,40} = 0.08$, $p=0.92$). Furthermore, heart rate was similar across the four time periods analyzed (i.e. pre-sound exposure, early sound exposure [first five R-R intervals during the sound exposure], late sound exposure [next five R-R intervals during the sound exposure], and post-sound exposure, [$F_{3,60} = 1.22$, $p=0.31$]). R-R intervals within a given time period were also similar ($F_{4,80} = 0.69$, $p=0.60$).

The average breathing frequency was approximately 11 breaths/min and did not differ significantly between the beginning and the end of the dive ($F_{1,16} = 2.85$, $p=0.1$). The main F statistic for the ANOVA that compared breathing rates, during the sham exposures, with breathing rates, during the first low (140 dB) and first high SLP (163 –166 dB) exposure, was also not significant ($F_{2,30} = 1.73$, $p=0.19$). This suggests that the LFWBS exposures did not significantly impact breathing frequency. However, a separate two-way repeated measures ANOVA performed on the respiratory frequencies prior to and during the first and last sound exposure showed that breathing rate was increased significantly by 12.6% (1 breath/min) ($F_{1,16} = 8.90$, $p <0.01$) during the sound exposure. At first, these analyses seem to contradict each other. However, they may be explained by the fact that during the majority of time over which the pre-sound exposure respiratory frequency was calculated, the divers were not performing the underwater RT test. In contrast, during the period when the sound was on and during the sham period, the divers had to perform the RT task and rate loudness and vibration. Thus, the additional cognitive and physical demands under the later condition likely resulted in the slight increase in breathing frequency noted in the second analysis.

When breathing rate during the different LFWBS exposures was correlated with State and Trait anxiety scores, the r-values ranged from –0.40 to 0.01. None of the correlations were significant ($p>0.05$).

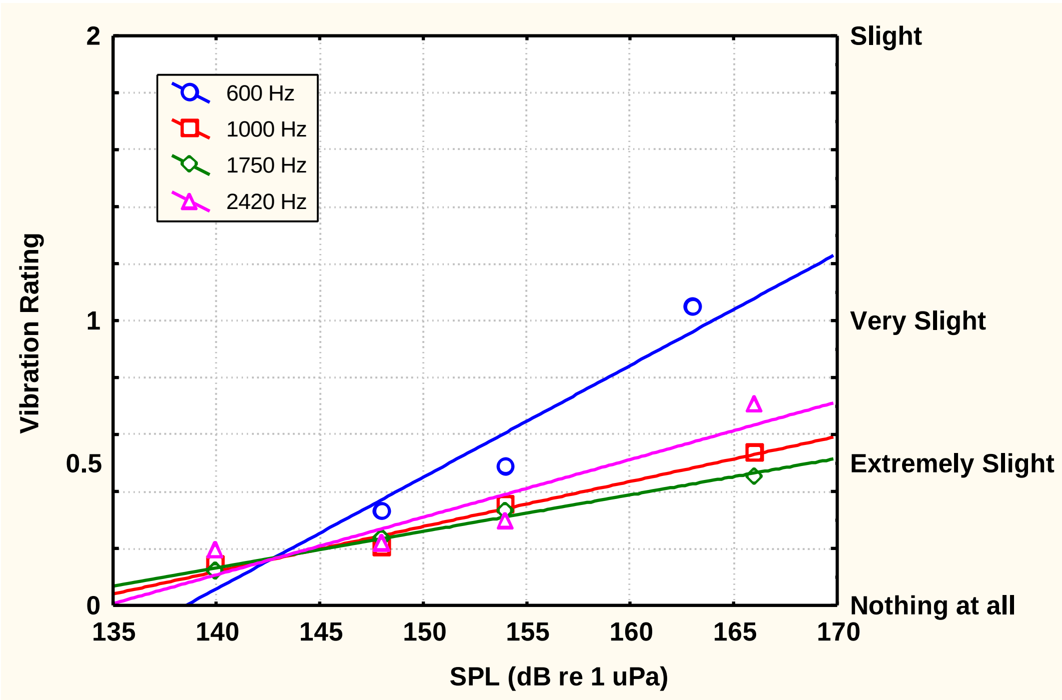

Figure 9. Vibration ratings by frequency for the LFWBS exposures. The data are means from 21 recreational divers. The lines through the data points were fitted using least squares linear regression. See Appendix F for the regression equations.

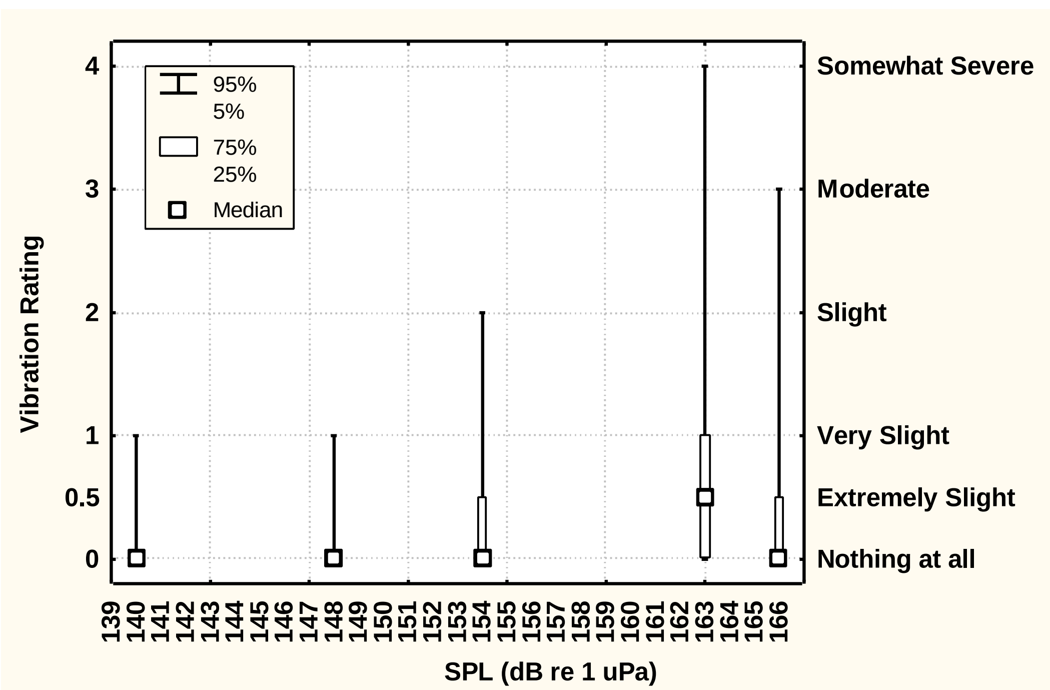

Figure 10. Median and percentile vibration ratings at each SPL for the LFWBS exposures. Data includes all frequencies and are for 21 recreational divers.

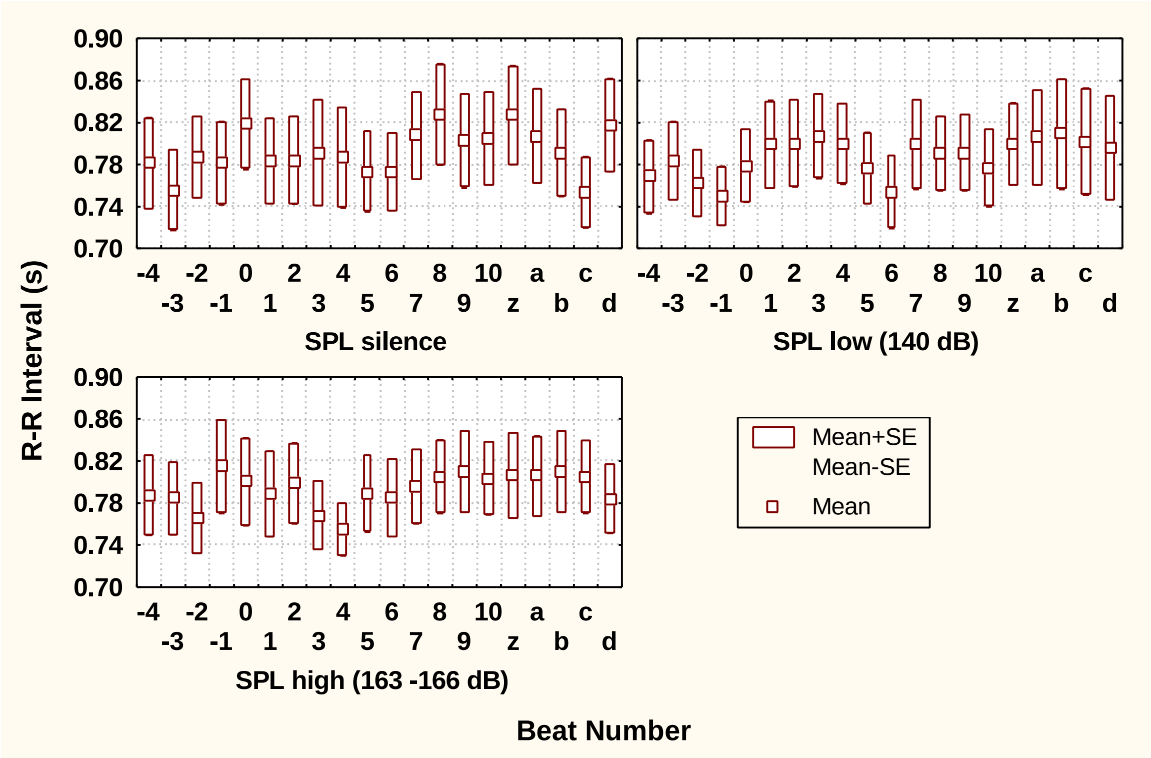

Figure 11. Group mean ± SE for R-R intervals recorded during the first sham (silence), low (140 dB) and high (163 – 166 dB) LFWBS exposures. Onset of the LFWBS stimulus occurs between R-R interval "0" and "1". While the sound was on for 28 s, only the first 10 R-R intervals during the sound exposure (i.e. 1 through 10) were subjected to statistical analysis. The LFWBS stimulus was switched off between the "z" and "a" R-R interval.

DISCUSSION

Our results indicate that the current group of recreational divers tolerated the underwater sound exposures well. There were no aborts or indications of panic resulting from the sound exposures. Furthermore, the subjects were able to continue the underwater RT test with only minor decrements in the speed or accuracy of responding, even during the highest intensity sound exposure. Although sound exposures above 154 dB SPL resulted in high ratings of loudness and reports of vibration, physiological measures of heart rate (HR) and breathing frequency remained unaffected by the underwater sound exposures. This latter finding suggests that under the current experimental conditions the subjects did not exhibit a significant startle response to the underwater sound exposures. Since we hypothesized that a startle response would be evident at the higher SPL exposures the following discussion focuses on possible reasons for our non-significant findings.

Previous studies, in which subjects have been unexpectedly exposed to in-air noise bursts, have elicited either an orienting reflex (OR), a defense reflex (DR) or a startle reflex (SR). The OR is reflected by a HR deceleration, whereas the DR and SR are characterized by long or short latency HR acceleration, respectively (Graham 1979). The type of response elicited is dependent upon the stimulus parameters, experimental design and instructions to subjects. In addition, conditioning of the cardiac DR versus OR has been related to the affective content of the stimulus (Gautier and Cook 1997; Cook et al. 1986), and there is evidence that the SR is potentiated by aversive emotional states (Cook et al. 1992). For further details on the physiological significance and theoretical construct of these reflexes or responses, the reader is referred to papers by Turpin (1986) and Barry and Maltzman (1985).

In our previous underwater diving studies, underwater sound presented at frequencies between 100 and 500 Hz at SPLs up to 157 dB provoked a temporary decrease in HR (Fothergill et al. 1998b). This HR deceleration was attributed to a normal non-habituating voluntary OR. In contrast to the findings of Fothergill et al. (1998b), the current study showed no evidence of a cardiac OR or SR. We can not discount the possibility that the underwater sounds elicited a DR, since HR measures beyond 5 beats post stimulus were not analyzed. The onset of the long latency cardiac acceleration, typical of a DR, usually occurs after at least 2 seconds following the sound stimulus. However, with initial exposure to a high intensity stimulus, HR may not reach a peak until 35 s after the stimulus (Turpin 1986). As the duration of sound exposures in the current study were much longer than the typical auditory startle stimuli used for air studies, any long latency HR responses will likely have been affected by possible reactions to the sound stimulus being switched off.

It is possible that the cardiac response to the sound in the previous experiment was dependent on voluntary attentional processes and the significance of the sound stimuli to the subjects. In the current experiments, subjects were told to ignore the sound stimulus and continue with the RT time task. Although they were informed that the sounds might be loud, they were not given any indication that they may be aversive. In contrast, during the experiments conducted by Fothergill et al. (1998b), subjects were required to attend to the stimulus and were asked to rate their level of aversion to the sound. Clearly, the instructions to the subjects in the two experiments were different, which may have induced differences in cortical set and expectations about the aversive nature of the sound. O'Gorman (1990) has suggested that whether or not a voluntary OR is elicited is dependent upon the subject' cortical set and the level of activation of the left hemisphere. Only when subjects are required to think actively about the stimulus is a common cortical set given to all subjects and consistent responding to be expected (O'Gorman 1990).

Further evidence of the effects of cortical set on HR responses to underwater sound were shown in the experiments conducted by Waltz and Fothergill (1999). Their findings are shown in figure 12. When subjects were exposed to 600 Hz sound at 163 dB, a clear increase in HR was evident by the 5th beat post stimulus when breathing air at 1 m. However, when the same subjects breathed a normoxic 23% N_2O mixture at 1 m, this short latency HR increase was no longer evident. It is thus possible that manipulation of cortical set or attention processes, by either inert gas narcosis or by a distracter task as in the case of the current experiment, can reduce or abolish the cardiac responses to an underwater sound stimulus.

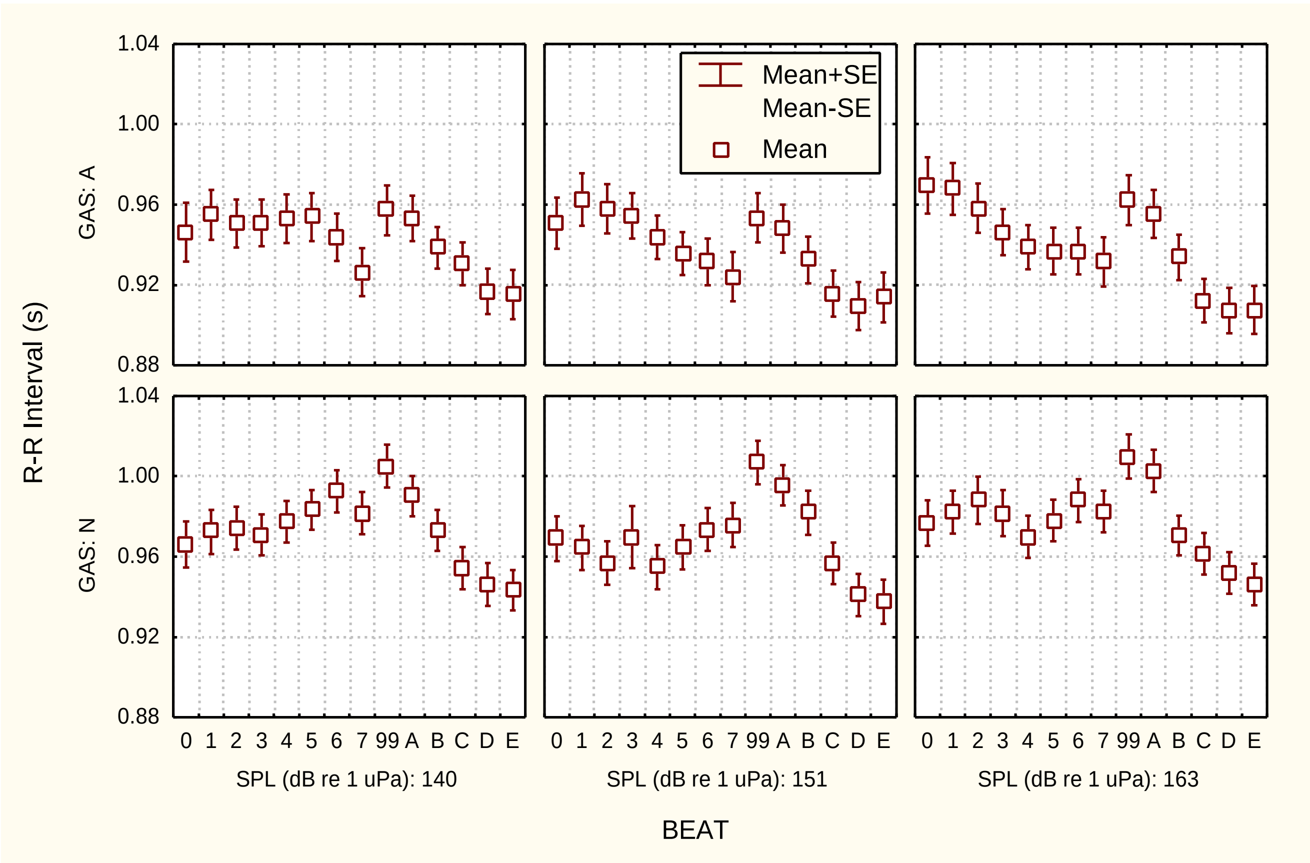

Figure 12. Group mean ± SE for R-R intervals recorded during exposures to different sound pressure levels of a 600 Hz underwater pure tone while breathing air at 1 m (Gas: A) or a normoxic 23% N_2O gas mixture (Gas: N) at the same depth. The data are for 29 US Navy Divers who participated in the study by Waltz and Fothergill (1999). Onset of the LFWBS stimulus occurs between beat "0" and "1". Beats 1 through 7 are during the sound exposure. The LFWBS stimulus was switched off between beat "99" and "a". Beats A through E were post stimulus. Note the difference in HR response during the sound presentations between the two different gas conditions (see text for further details).

Our data shows that the underwater sound stimuli significantly increases RT, and, at the highest SPLs, increases the number of choice errors on a two-choice RT time task. Similar findings have also been found for in-air acoustic startle experiments (Fitzpatrick and Paige 1997; Vlasak 1969). Fitzpatrick and Paige (1997) found that a 110 dB re 20 µPa 50-ms burst of white noise increased RT to the first button press in a sequential memory test by 220 ms. Furthermore, subjects with larger orbicularis oculi and sternocleidomastoid EMG amplitude responses to the startling stimuli showed greater RT slowing. Interestingly, changes in HR evoked by the startling stimulus were not related to RT slowing. Vlasak (1969) also noted that simple RT lengthened following a loud burst of sound from a klaxon-hoot. The sound intensity of the klaxon-hoot was 100 dB re 20 µPa at 1-m distance with a mean frequency of 300–400 Hz and 2000–3000 Hz. In the same set of experiments, Vlasak also noted that the number of errors on a simple math test increased significantly during the first 15 seconds following the startle stimulus.

It thus seems that a strong sound stimulus can temporarily interrupt the train of thought of an ongoing activity. Furthermore, if the startle stimulus is loud enough, some individuals may make mistakes in decision making immediately following the stimulus. However, our subjects showed only small decrements on the RT task in response to the underwater sound stimuli, that were largely independent of the SPL and frequency. Thus, from a practical perspective, these minor temporary effects on simple mental activity following exposure to the levels of underwater sound used in the current experiments are of little practical concern.

The only performance measure showing a post-dive decrement was RT on the matching-to-sample test which lengthened by 17%. The reason for this performance decrement is unclear. One possibility is that it is a Type I error or a result of an outlier. Analysis of the group data showed that the post-dive standard deviation for RT on this subtest was almost double that of the pre-dive standard deviation. However, the difference between the two standard deviations was not significant. Furthermore, inspection of individual RTs did not reveal any particular remarkable outliers in the post dive data set. Of the 21 subjects, 15 showed longer RTs, 2 subjects were within 10 ms of their pre-dive score and 4 subjects improved on the matching-to-sample test post-dive. As a precaution against committing a type I error, alpha for this test was set at 0.01 rather than 0.05. Thus, it seems likely that the slowing of RT on this test was due to factors other than statistical error.

Recently, Lowe and Reeves (1999) used the ANAM 2000 neuropsychological test battery to determine if cognitive function was affected during a 1000 fsw chamber saturation dive. Results of their study showed that Matching-To-Sample was the only subtest to show a significant performance decrement at depth. The Matching-To-Sample test was also found to be the most sensitive test for detecting cognitive changes associated with decompression stress in a diver who exhibited delayed decompression symptoms following accelerated decompression from a saturation dive (Lowe et al., 1999). In the present study, all of the divers were exposed to the LFWBS during the dive. Without additional data from divers performing the experiment without the sound exposure, we can not confidently distinguish the cause of the decreased performance on the matching-to-sample test between the stresses of the dive and the effects of LFWBS. At a minimum, it would seem that one or both of these factors may have contributed to the post-dive performance decrement on the matching-to-sample task.

Study Limitations

When interpreting the above findings we acknowledge some of the limitations of the study. First, as all subjects were volunteers, it is uncertain how well our subject population represents the responses of the general recreational diver population. The state and trait anxiety scores indicate that our subject population was less anxious than the general population of military recruits. It is possible that the physical and psychological aspects of diving tend to attract low-anxiety personalities and/or dissuade highly anxious individuals from conducting or completing their dive certification. It may also be that divers learn to inhibit state anxiety since it tends to disrupt performance under water (Baddley 1972; Mears and Cleary 1980). In addition, it is likely that highly anxious recreational divers would be less likely to participate in the current study due to the potential aversive nature of the sound stimulus. There is evidence that high trait anxiety individuals exhibit significantly larger startle responses than low trait anxiety individuals (Filion and Brown 1997). Thus, the low anxiety scores of our diver population may be another reason for the lack of a startle response in the current study.

A second limitation of the study is that its is ethically unacceptable to place novice divers in a situation where they would be completely unaware that they were about to be exposed to a potentially aversive underwater sound stimulus. Consequently, subjects were made aware that, through the informed consent process, they would be exposed to loud sounds underwater. This likely resulted in some *a priori* expectation by the subject that may have reduced the chance of observing a startle response. Clearly, this expectation would be absent in a diver exposed to a sonar signal while conducting a recreational dive in the open ocean. Post-dive reports from the subjects did, however, indicate that one-third of the subjects were startled by one or more of the underwater sound stimuli. Although the subjective reports are not reflected in our physiological measures of startle, more sensitive physiological measures of startle (e.g. eye blink reflexes) may have indicated that startle was present.

Other post dive comments revealed that approximately one-half of the subjects said they would surface if they heard these sounds during a recreational dive. Interestingly, at the highest SPLs only two subjects gave loudness ratings of 10, which indicated they would immediately abort an open ocean dive because of the sound exposure.

Proposed SPL limits for exposure to 600 –2500 Hz LFWBS in recreation divers

Although the mean HR data showed no evidence of a cardiac startle response, many individuals still found some of the underwater sound stimuli startling or annoying. Bjok (1999) has shown that the annoyance resulting from a sound stimulus is not necessarily associated with the evoked startle response. Thus,when behavioral or physiological indications of startle are not evident, we need to rely on the subject's subjective responses to determine acceptable exposure levels to underwater sound. This approach was used in setting the SPL exposure limits to LFWBS for recreational divers in the US Navy's SURTASS LFA Environmental Impact Statement (2001). A similar approach is adopted here to help define acceptable SPL exposure limits to 600 – 2500 Hz LFWBS.

Using the subject's loudness responses, figure 13 shows the change in percentage of loudness ratings that exceed 'Very Severe' as a function of SPL. A rating of 7, or 'Very Severe' loudness, was chosen as the high rating cut off point, to conform with the convention used for setting SPL exposure limits to 100 – 500 Hz LFWBS (Cudahy et al., 2002, Department of the United States Navy 2001). Furthermore, since a loudness rating of 10 was considered the point at which a diver would abort an open ocean dive, choosing a value less than 10 as the high rating cut off will provide a level of conservatism when estimating the dive abort risk for a given sound exposure. Figure 13 shows that only one subject rated the loudness of the LFWBS at 154 dB, greater than ‘Very Severe’. However, once the SPLs exceed 154 dB there was a sharp increase in the number of subjects providing loudness ratings greater than ‘Very Severe’. These data suggest that if recreational divers are exposed to 600–2500 Hz LFWBS at SPLs in excess of 154 dB, there is an increased risk that a diver will abort a dive because of the sound. It is therefore recommended that the maximal acceptable SPL at 600 –2500 Hz LFWBS for recreational divers be no higher than 154 dB. Based upon the data in Figure 8 it is estimated that only 5% of divers would rate the loudness of 600–2500 Hz LFWBS greater than ‘Severe’ at an SPL of 154 dB.

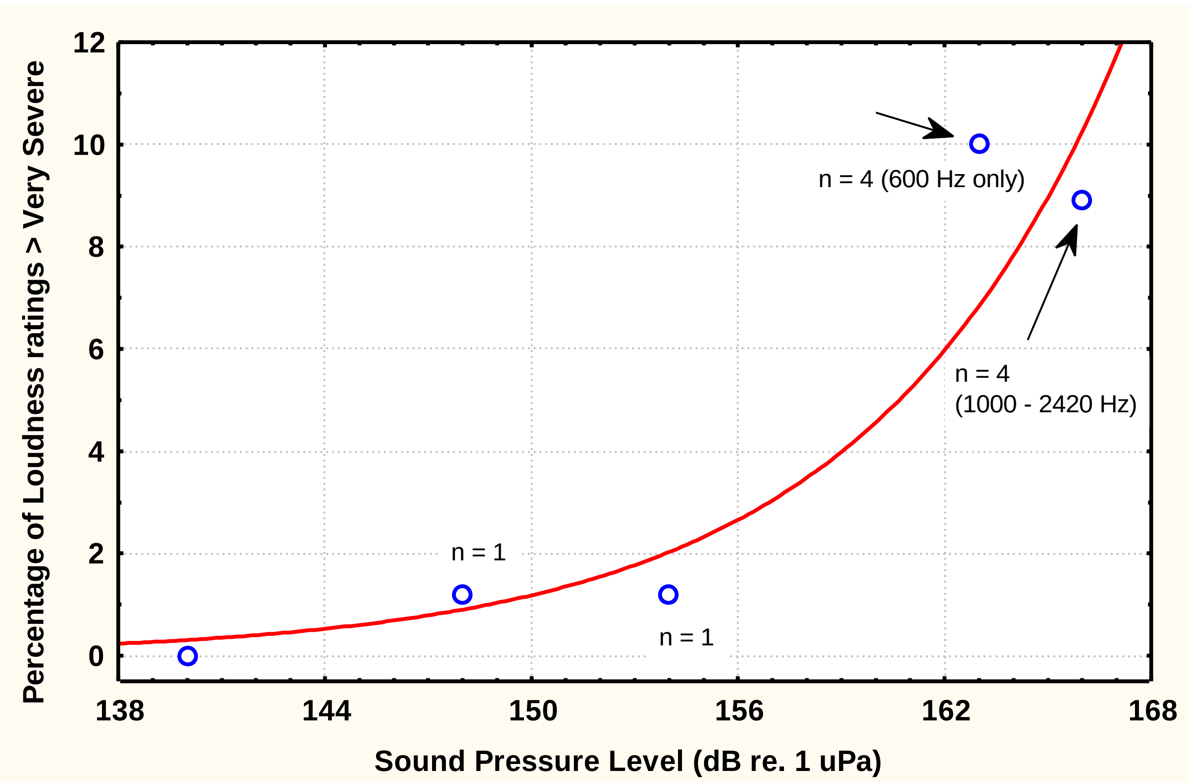

Figure 13. Percentage of loudness ratings greater than 'Very Severe' versus SPL. The line through data points is fitted with an exponential. (n = the number of subjects contributing to each data point).

The proposed maximum acceptable SPL for the 600–2500 Hz frequency region is well below the minimum SPL at which bare-headed divers have reported physiological effects (other than sensations of vibration) from underwater sound exposures at these frequencies. In a study conducted by Parvin et al., (2001), bareheaded divers were exposed to underwater sound up to a maximum SPL of 191 dB re. 1µPa in the frequency range from 800–2250 Hz. In their study, the minimum SPL causing termination of the sound exposures was between 176 and 185 dB. The reasons given for termination were that the sound affected balance and resulted in dizziness during the exposures. The effects subsided once the sound was removed. Using the subjective comments from their divers and a 5 out of 10 loudness rating, Parvin et al., (2001) commented that the maximum acceptable exposure level for recreational divers to underwater sound at frequencies from 880 Hz to 2250 Hz ranged between 142 and 153 dB. It should be noted that although Parvin et al., (2001) used a 10-point loudness scale, the descriptive anchors on the scale were different than those used in the present study. In the current study, a rating of 5 was given if the diver perceived the loudness of the sound to be 'Severe.' In contrast, 5 on the loudness scale used by Parvin et al., (2001) indicated a sound that was "loud, but not disturbing." Despite the difficulties in comparing the two data sets, our proposed recreational diver SPL exposure limits to 600–2500 Hz LFWBS are not far removed from the upper limit recommended by Parvin et al., (2001).

CONCLUSIONS

Waterborne sound at frequencies from 600-2420 Hz at SPLs up to 166 dB for up to 28 s is tolerated well by bare headed SCUBA divers. Other than very slight sensations of vibration, which are greatest at the lower end of the frequency range, there is minimal physiological impact of these sound exposures. Furthermore, at SPLs below 166 dB there is little impact of these LFWBS exposures on simple cognitive performance. Although none of the divers aborted the dive because of the sound exposures, an increasing number of subjects gave high loudness ratings (">Very Severe") once the SPL exceeded 154 dB. Based upon the loudness ratings it is recommended that the maximal acceptable SPL to 600–2500 Hz LFWBS for recreational divers be no higher than 154 dB re 1 μPa.

REFERENCES

Baddeley, A.D. 1972. Selective attention and performance in dangerous environments. The British J. Psych. 64: 537-546.

Barry, J.R. and I. Maltzman. 1985. Heart rate deceleration is not an orienting reflex; heart rate acceleration is not a defensive reflex. Pav. J. Biol. Sci. 20: 15-28.

Björk, E.A. 1999. Startle, annoyance and psychophysical responses to repeated sound bursts. Acoustica 85: 575-578.

Borg, G.A.V. 1982. Psychophysical bases of perceived exertion. Med. Sci. Sports and Exercise 14: 377-381.

Cook, III, E.W., R.L. Hodes, and P.J. Lang. 1986. Preparedness and phobia: Effects of stimulus content on human visceral conditioning. J. Ab. Psych. 100: 5-13.

Cook, III, E.W., T.L. Davis, L.W. Hawk, E.L. Spence and C.H. Gautier. 1992. Fearfulness and startle potentiation during aversive visual stimuli. Psychophysiology, 29: 633-645.

Crum, L.A., and Y.I Mao. 1993 Acoustically enhanced bubble growth at low frequencies and its implications for human diver and marine mammal safety. Technical Report No. C-193. Naval Submarine Medical Research Laboratory.

Cudahy E.A., E. Hansen and D.M. Fothergill. (in review). Summary report on the bioeffects of low frequency underwater sound. Naval Submarine Medical Research Laboratory, Technical Report, Groton, CT, USA.

Department of the United States Navy (2001), Executive Summary, Final Overseas Environmental Impact Statement and Environmental Impact Statement for Surveillance Towed Array Sensor System Low Frequency Active (SURTASS LFA) Sonar, January 2001, Report available at URL http://www.surtass-lfa-eis.com/.

Duykers, L.R.B. and J.L. Percy. 1978. Lung resonance characteristics of submerged mammals. Journal of Acoustical Society of America. 64: S97.

Englund, C.E., D.L. Reeves, C.A. Shingledecker, D.R. Thorne, K.P. Wilson and F.W. Hegge. 1987. The unified tri-service cognitive performance assessment battery (UTC-PAB): I. Design and specification of the battery. Report no. NHRC-TR-87-10. Naval Health Research Center, San Diego, CA.

Filion, D.L. and C.E. Brown. 1997. Trait anxiety and individual differences in startle modification. Psychophysiology 34 (Suppl 1): S33.

Fitzpatrick, D.F., and S.R. Paige. 1997. Effects of startle on a motor programming task. Psychophysiology 34 (Suppl 1): S34.

Fothergill, D.M, J.R. Sims, and M.D. Curley. 1998a. Diver aversion to low frequency sound. Undersea and Hyperbaric Medicine 25 (Suppl): 38-39.

Fothergill, D.M., J.R. Sims, and M.D. Curley. 1998b. Heart rate changes during exposure to low frequency underwater sound. Carter, N and Soames Job R.F. (Eds). Noise Effects '98, 7th International Congress on Noise as a Public Health Problem. Vol. 1. Noise Effects '98 PTY Ltd., Sydney, Australia. pp. 302-305.

Fothergill, D.M., M.D. Waltz, and S.E. Forsythe. 2000. Diver aversion to low frequency underwater sound phase II: 600 – 2500 Hz. Undersea and Hyperbaric Medicine 27 (Suppl): 18.

Fothergill D.M., M.D. Waltz, and S.E. Forsythe.. 2001a. Effects of signal duration and inert gas narcosis on diver aversion to low frequency underwater sound. Undersea and Hyperbaric Medicine 28 (Suppl): 72.

Fothergill, D.M., J.R. Sims, and M.D. Curley. 2001b. Recreational SCUBA divers' aversion to low frequency underwater sound. Undersea and Hyperbaric Medicine 28: 9-18.

Gautier, C.H. and E.W. Cook III. 1997. Relationships between startle and cardiovascular reactivity. Psychophysiology, 34: 87-96.

Graham, F.K. 1979. Distinguishing among orienting, defence and startle reflexes. In Van Olst, E.H and J.F. Orlebeke (eds): The Orienting Reflex in Humans. Lawrence Erlbaum, Hillsdale, pp 137-167.

Lowe, M.A., and D.L. Reeves. 1999. At depth evaluation of a computerized neuropsychological assessment tool: deep dive 98. Undersea and Hyperbaric Medicine 26 (Suppl): 18.

Lowe, M.A., D.G. Southerland, and D.L. Reeves. 1999. Computer-based neuropsychological findings in a patient with DCS following accelerated decompression from a saturation dive: a case study. Undersea and Hyperbaric Medicine 26 (Suppl): 17.

Mears, J.D. and P.J. Cleary. 1980. Anxiety as a factor in underwater performance. Ergonomics 23: 549-557.

Nyborg, W.L. 1993. Estimates of limits to temperature rise. In F. M. Pestorius (Au), Effects of low frequency waterborne sound on divers (Technical Report ARL-TR-96-5). Austin, Texas: University of Texas at Austin, Applied Research Laboratory.

Navy Occupational Safety and Health Program Manuel. OPNAV INSTRUCTION 5100.23 D. October 11, 1994.

O'Gorman, J.G. 1990. Individual differences in the orienting response: nonresponding in nonclinical samples. Pav. J. Biol. Sci. 25:104-108.

Parvin, S. J., J. R. Nedwell, K. Needham, A.W.H. Turnpenny, A. J. Thomas, and S.L. Searle. 1994. The effects of low frequency sonar transmissions on divers and ichthyofauna: Hyperbaric and open water diver studies and the noise exposure of species of fish. United Kingdom: Defense Research Agency, Report #DRA/AWL/CR941010/V1.0.

Parvin, S. J., S.L. Searle and M.J. Gilbert. 2001.Exposure of divers to underwater sound in the frequency range from 800 to 2250 Hz. Undersea and Hyperbaric Medicine 28(Suppl): 44.

Reeves, D., T. Elsmore, K. Winter, R. Kane, and J. Bleiberg. 1998. ANAM 2000 (Beta 1.0) User's Manual. NCRF/NRH Special Report 98-01. The National Rehabilitation Hospital (NRH), Washington, DC.

Rogers, P.H., G.W. Caille, T.N. Lewis. 1994. Response of the lungs to low frequency underwater sound. Presented at Naval Submarine Medical Research Laboratory Meeting on The Effects of Low-Frequency Water-Borne Sound on Divers, Naval Submarine Base, Groton, CT. June 29, 1994.

Russell, K.L., and M.E. Knafelc. 1995. Low frequency water-borne sound: manned diving series. Navy Experimental Diving Unit Technical Report No. 10-95. Panama City, FL.

Sims, J.R., and D.M. Fothergill. 1999. The effect of low frequency underwater sound on diver safety. Undersea and Hyperbaric Medicine 26 (Suppl): 62-63.

Sims, J.R., D.M. Fothergill, M.D. Curley. 1998a. Degree of aversion to low-frequency waterborne sound in non military trained divers. NSMRL CPHS Protocol DOD 30341.

Sims, J.R., D.M. Fothergill, M.D. Curley. 1998b. Diver aversion to the duration of underwater low frequency sonar. In: Carter, N. and Soames Job, R.F. (Eds). Noise Effects '98, 7th International Congress on Noise as a Public Health Problem, Vol. 1. Noise Effects '98 PTY Ltd., Sydney, Australia. pp. 411-414.

Sims, J.R., D.M. Fothergill, M.D. Curley. 1999. Effects of a neoprine wetsuit hood on low frequency underwater hearing thresholds. The Journal of the Acoustical Society of America 105: 1298.

Smith, P. F., R. Sylvester, F. Baran, and C. Steevens. 1996. Development of a General Hearing Conservation Standard for Diving Operations: Experiment I Comparison of Temporary Auditory Threshold Shifts Induced by Intense Tones in Air and Water, Report #1203, Naval Submarine Medical Research Laboratory, Naval Submarine Base New London, CT.

Spielberger, C. D. 1983. State-Trait Anxiety Inventory for Adults. Consulting Psychologists Press, Inc.

Steevens, C.C., C.I. Schlichting, and F. Baran. 1994a. Effects of low-frequency water-borne sound on divers: physiological monitoring during torso exposure. Presented at Naval Submarine Medical Research Laboratory Meeting on The Effects of Low-Frequency Water-Borne Sound on Divers, Naval Submarine Base, Groton, CT. June 29, 1994.

Steevens, C.C., M.E. Knafelc, and J. Clark. 1994b. Effects of low-frequency water-borne sound on divers: physiological monitoring during immersion at depth. Presented at Naval Submarine Medical Research Laboratory Meeting on The Effects of Low-Frequency Water-Borne Sound on Divers, Naval Submarine Base, Groton, CT. June 29, 1994.

Steevens, C.C., R. Sylvester and J. Clark. 1997. Effects of low-frequency water-borne sound on divers: Open water trial. Report #1208, Naval Submarine Medical Research Laboratory, Naval Submarine Base New London, CT.

Steevens, C.C., K.L. Russell, M.E. Knafelc, P.F. Smith, E.W. Hopkins, and J.B. Clark. 1999. Noise-induced neurologic disturbances in divers exposed to intense water-borne sound: two case reports. Undersea Hyperbaric Medicine 26: 261-265.

Suki, B., R.H. Habib, and A.C. Jackson. 1994. Effects of low frequency (f<2000 Hz) waterborne sound on divers: wave propagation in the airways. Presented at Naval Submarine Medical Research Laboratory Meeting on The Effects of Low-Frequency Water-Borne Sound on Divers, Naval Submarine Base, Groton, CT. June 29, 1994.

Turpin, G. 1986. Effects of stimulus intensity on autonomic responding: The problem of differentiating orienting and defence reflexes. Psychophysiology 23: 1-14.

Tyler Jr, G.D. 1992. The emergence of low-frequency active acoustics as a critical antisubmarine warfare technology, John Hopkins APL Technical Digest 13: 145-159.

U.S. Navy Diving Manual Revision 4, 1999. SS521-AG-PRO-010, 0910-LP-708-8000, Published by Direction of Commander, Naval Sea Systems Command.

Verillo, R.T., S.J. Bolanowski, F. Baran, and P.F. Smith. 1994. The effects of underwater environmental conditions on vibrotactile thresholds. Journal of the Acoustical Society of America, 100(1), 651-658.

Vlasak, M. (1969). Effect of startle stimuli on performance. Aerospace Med. 40: 124-128.

Waltz, M.D. and D.M. Fothergill. 1999. Aversion to low-frequency (500 – 2500 Hz) waterborne sound in U.S. Navy divers. Naval Submarine Medical Research Laboratory human use Protocol DOD# 30358.

ACKNOWLEDGEMENTS

Supported by the Office of Naval Research Code 341. The views expressed in this report are those of the authors and do not reflect the official policy or position of the Department of the Navy, the Department of Defense or the US Government. This work was conducted while Dr. Fothergill was on assignment leave from the Research Foundation of the State University of New York at Buffalo through an Assignment Agreement with the Naval Submarine Medical Research Laboratory, Groton, CT. The work was done by US government employees as part of their official duties and therefore cannot be copyrighted.

The dedicated and professional efforts of Mr. Rick Donlon, MDV (Ret), BMC(DV) Walter Von Borstel, EM2(DV) Lloyd LeNormand and CDR Keith Wolgemuth MSC in providing diving supporting are acknowledged and greatly appreciated. Support and training on the ANAM 2000 neuropsychological test battery was provided by LT Michael Low MSC. In particular, his assistance in the statistical analysis and interpretation of the ANAM 2000 data is greatly appreciated. Our thanks are also extended to Linda Hughes and HM3 Michael McFadden who administered the audiograms to the subjects. The tireless efforts of Dr. Steven Forsythe, and John Armstrong at the Naval Underwater Warfare Center, RI, during modification and development of the software for sound presentation and data collection were instrumental in contributing to the success of this study. Finally, we especially extend our thanks to the subjects who volunteered their time to participate in this study.

Appendix A:
ADVERTISEMENT PUBLISHED IN THE PLAN OF THE WEEK OF VARIOUS COMMANDS REQUESTING DIVE VOLUNTEERS FOR THE STUDY

Active Duty SCUBA Divers needed for Navy dive study!

Recently the U.S. Navy produced an environmental impact statement on the use of the Surveillance Towed Array (SURTASS) Low Frequency Active Sonar (LFA) System. The SURTASS LFA sonar system uses specialized sounds and echo detection methods to detect and track submarines. As these low frequency sonar sounds can travel long distances, some of the sound may reach popular dive sites. Research conducted by the Naval Submarine Medical Research Laboratory (NSMRL) provided important data that contributed to development of the environmental impact statement. In particular, human diving studies conducted by NSMRL researchers, with the aid of recreational diver volunteers as subjects, helped to provide guidance for the operational use of the SURTASS LFA sonar system.

Due to recent developments in sonar technology, NSMRL scientists are currently extending their research into a higher frequency region than that studied in the human dive experiments for the SURTASS LFA sonar system. In the past two years NSMRL researchers have conducted several successful experiments investigating divers' subjective responses to different levels of sound within the 600 to 2500 Hz frequency region. Experiments were conducted with the help of US Navy trained divers as volunteer subjects.

The objective of these human dive experiments is to provide guidance on the acceptable level of sound that can be used when using these sonars near potential dive sites. As this guidance needs to apply to the general diver population, the final set of diving experiments planned for July of this year will require civilian trained/certified divers both, male and female, (i.e. NAUI, PADI or equivalent certification) as experimental subjects. The study is being conducted at the NSMRL, on Submarine Base New London, CT and at Dodge Pond Niantic, CT, between July 12th and July 27th. The purpose of the study is to see if waterborne sound in the frequency range 600 to 2500 Hz distracts a diver's ability to concentrate on a simple task. Testing is noninvasive (i.e. no blood draws) and involves one day of diving and a 30 min hearing test on the morning of the dive and the morning after the dive. Volunteers may be eligible to receive experimental stress pay following their participation in the diving portion of this study.

If you are over 18 and are active duty military or Coast Guard, and have a civilian diving qualification, and wish to participate in this research, please contact:

Dr. David Fothergill at 860 694 2536
Email fothergill@NSMRL.NAVY.MIL

or Rick Donlon MDV at 860 694 4907
Email donlon@NSMRL.NAVY.MIL

Appendix B:

MEDICAL DATA FORM

Name: ____

SSN___________________

Sex (Circle) Male Female

1. Age (years)_______ (months)_______ DOB_____________
2. Weight (lbs.)_______
3. Height (inch)_______
4. Are you currently qualified to dive? Circle Yes No:
5. Level of certification_________________

Years of diving experience____________ Approximate date of last dive__________

Approximate number of dives conducted since certification___________

Are you a U.S. military trained diver? Circle Yes No

6. What is your NEC? __________
7. Have you ever had an episode of AGE (arterial gas embolism) or DCS (decompression sickness)? Circle Yes No If yes, please give approximate dates and details.____

____

____

____

____

8. Do you have any neural deficits? (patches of numb or tingling skin, motor weakness, memory disturbance, seizures, tumor or aneurysm, stroke, spinal cord injury) Circle:Yes No If yes, please describe.

____

____

____

9. Have you ever had surgery? Circle Yes No If so, describe what organ system or body part, dates and reasons.

____

____

____

____

____

10. Do you have any metal objects/hardware in your body? (i.e. screws, rods, pins or shrapnel etc.)

Circle Yes No If yes, what and where?____

11. Smoking Status: Circle Non Smoker Occasional Smoker Smoker 1ppd 2ppd >2ppd

12. Do you have any chronic orthopedic complaints? i.e. knee pain, low back pain, chronic pain related to injury/accident etc. Circle Yes No If yes please explain

____

____

____

____

13. Have you ever suffered a head injury resulting in: (Circle) concussion loss of consciousness seizure? Please give dates and details:

____

____

____

____

14. Do you have any hearing difficulties or have you had ear surgery or chronic ear infections? Circle: Yes No . If yes, please explain:

____

____

____

____

____

15. Do you have any breathing, lung or heart problems (asthma, emphysema, punctured lung, bronchitis, arrhythmia, congestive heart failure, heart attack, high blood pressure, fainting)? If

yes, please explain:

16. Are you currently under medical care or taking any medications? Circle Yes No. If yes, please list medications and indications.

17. Do you have any other conditions such as sickle cell disease, polycythemia, leukemia, claustrophobia, psychosis, panic disorder, drug or alcohol abuse? If yes please explain.

18. Are you currently pregnant? Circle: Yes No

Have you been treated for any of the above conditions or are you currently under the care of a physician or health care provider?

Appendix C

GUIDELINES FOR RECREATIONAL SCUBA DIVER'S PHYSICAL EXAMINATION

Instructions to the Physician:

Recreational scuba (self-contained underwater breathing apparatus) diving has an excellent safety record. To maintain this status it is important to screen student divers for physical deficiencies that could place them in peril in the underwater environment.

The Recreational Scuba Diver's Physical Examination contains elements of medical history, review of systems and physical examination. It is designed to detect conditions that put a diver at increased risk for decompression sickness, pulmonary overinflation syndrome with subsequent cerebral gas embolization and loss of consciousness, that could lead to drowning. Additionally, the diver must be able to withstand some degree of cold stress, cope with the optical effects of water and have a reserve of physical and mental abilities to deal with possible emergencies.

The history, review of systems and physical examination should include, as a minimum, the points listed below. The list of contraindications, relative and absolute, is not all-inclusive. It only contains the most commonly encountered medical problems. The brief introductions should serve to alert the physician to the nature of medical problems that put the diver at risk, and (lead him) to consider the individual patient's state of health.

Diagnostic studies and specialty consultations should be obtained as indicated to satisfy the physician as to the diver's status. A list of references is included to aid in clarifying issues that arise. Physicians at the Diver Alert Network (DAN) are available for consultation by phone (919) 684-2948 during normal business hours. For emergency calls 24 hours, 7 days a week call (919) 684-8111.

Some conditions are absolute contraindications to scuba diving. Conditions that are absolute contraindications place the diver at increased risk for injury or death. Others are relative contraindications to scuba that may be resolved with time and proper medical intervention. Ultimately the physician should decide with the individual, based on his knowledge of the patient's medical status, whether the individual is physically qualified to participate in scuba diving.

Remember at all times that scuba is a recreational sport, and it should be fun, not a source of morbidity or mortality.

CARDIOVASCULAR SYSTEMS

Relative Contraindications: The diagnoses listed below potentially render the diver unable to meet the exertional performance requirements likely to be encountered in recreational diving. The diagnoses listed may lead the diver to experience cardiac ischemia and its consequences. Formalized stress testing is encouraged if there is any doubt regarding physical performance capability. The suggested minimum criteria for stress testing in such cases are 13 METS. Failure to meet the exercise criteria is disqualifying. Conditioning and retesting may make later qualification possible.

- History of CABG or PCTA for CAD
- History of myocardial infarction
- Hypertension

- History of dysrhythmias requiring medication for suppression
- Valvular regurgitation
- Asymptomatic mitral valve prolapse
- Pacemakers - The pathologic process that necessitated pacing should be addressed regarding the fitness to dive. Finally in those instances that the problem necessitating pacing does not preclude diving, will the diver be able to meet the performance criteria? Note: Pacemakers must be certified by the manufacturer as able to withstand the pressure changes involved in recreational diving (to depths of 130 feet of seawater).

Absolute Contraindications.- Various gas emboli produced during decompression may cross intracardiac shunts and enter the cerebral circulation with potentially catastrophic results. Asymmetric septal hypertrophy and valvular stenosis may lead to the sudden onset of unconsciousness during exercise.

- Congestive heart failure

PULMONARY

Any process or lesion that impedes airflow from the lung places the diver at risk for pulmonary overinflation with alveolar rupture and the possibility of cerebral air embolization. Asthma (reactive airway disease), COPD cystic or cavitating lung diseases all may lead to air trapping. Spirometry, provocative tests such as methacholine challenge and other studies to detect air trapping should be carried out to establish to the examining physician's satisfaction that the diver is not at risk. A pneumothorax that occurs or recurs while diving is catastrophic. As the diver ascends, air trapped in the cavity expands rapidly producing a tension pneumothorax.

Relative Contraindications:

- History of prior asthma or reactive airway disease (RAD)*
- History at exercise/cold induced bronchospasm (EIB)*
- History of solid, cystic or cavitating lesion*
- Pneumothorax secondary to thoracic surgery,* trauma or pleural penetration,* previous overinflation injury
- Restrictive disease**

(*Air trapping must be excluded) (**Exercise testing necessary)

Absolute Contraindications:

- Active RAD (asthma), EIB, COPD or history of the same with abnormal PFTs or positive challenge
- Restrictive diseases with exercise impairment
- History of spontaneous pneumothorax

NEUROLOGICAL

Neurologic abnormalities that affect a diver's ability to perform exercise should be assessed individually based on the degree of compromise involved.

Relative Contraindications:

- Migraine headaches whose symptoms or severity impair motor or cognitive function
- History of head injury with sequelae other than seizure
- Herniated nucleus pulposus
- Peripheral neuropathy
- Trigeminal neuralgia
- History of spinal cord or brain injury without residual neurologic deficit
- History of cerebral gas embolism without residual pulmonary air trapping has been excluded
- Cerebral palsy in the absence of seizure activity

Absolute Contraindications: Abnormalities where the level of consciousness is subject to impairment put the diver at increased risk of drowning. Divers with spinal cord or brain abnormalities where perfusion is impaired are at increased risk of spinal cord or cerebral decompression sickness.

- History of seizures other than childhood febrile seizures
- Intracranial tumor or aneurysm
- History of TIA or CVA
- History of spinal cord injury, disease or surgery with residual sequelae
- History of Type II (serious and/or central nervous system) decompression sickness with permanent neurologic deficits

OTOLARYNGOLOGICAL

Equalization of pressure must take place during ascent and descent between ambient water pressure and the external auditory canal, middle ear and paranasal sinuses. Failure of this to occur results at least in pain and in the worst case rupture of the occluded space with disabling and possible lethal consequences.

The inner ear is fluid filled and therefore noncompressible. The flexible interfaces between the middle and inner ear, the round and oval windows, are however subject to pressure changes. Previously ruptured but heated round or oval window membranes are at increased risk of rupture due to failure to equalize pressure or due to marked overpressurization during vigorous or explosive Valsalva maneuvers.

The larynx and pharynx must be free of an obstruction to airflow. The laryngeal and epiglottic structures must function normally to prevent aspiration.

Mandibular and maxillary function must be capable of allowing the patient to hold a scuba mouth piece. Individuals who have had mid-face fractures may be prone to barotrauma and rupture of the air filled cavities involved.

Relative Contraindications:

- Recurrent otitis externa
- Significant obstruction of external auditory canal
- History of significant cold injury to pinna
- Eustachian tube dysfunction
- Recurrent otitis media or sinusitis
- History of TM perforation
- History of tyrnpanoplasty
- History of mastoidectomy
- Significant conductive or sensorineural hearing impairment
- Facial nerve paralysis, not associated with barotrauma
- Full prosthodontic devices
- History of mid-face fracture
- Unhealed oral surgery sites
- History of head and/or neck therapeutic radiation
- History of temperomandibular joint dysfunction

Absolute Contraindications:

- Monomeric TM
- Open TM perforation
- Tube myringotomy
- History of stapedectomy
- History of ossicular chain surgery
- History of inner ear surgery
- History of round window rupture
- Facial nerve paralysis secondary to barotrauma
- Inner ear disease other than presbycusis
- Uncorrected upper airway obstruction
- Laryngectomy or status post partial laryngectomy
- Tracheostomy
- Uncorrected laryngocele
- History of vestibular decompression sickness

GASTROINTESTINAL

Relative Contraindications: As with other organ systems and disease states, a process that debilitates the diver chronically may impair exercise performance. Additionally diving activity may take place in areas remote from medical care. The possibility of acute recurrences of disability or lethal symptoms must be considered.

- Peptic ulcer disease
- Inflammatory bowel disease

- Malabsorption states
- Functional bowel disorders
- Post gastrectomy dumping syndrome
- Paraesophageal or hiatal hernia

Absolute Contraindications: Altered anatomical relationships secondary to surgery or malformations that lead to gas trapping may cause serious problems. Gas trapped in a hollow viscous expands as the giver surfaces and can lead to rupture or in the case of the upper GI tract, emesis. Emesis underwater may lead to drowning.

- High grade gastric outlet obstruction
- Chronic or recurrent small bowel obstruction
- Enterocutaneous fistulae that do not drain freely
- Esophageal diverticula
- Severe gastroesophageal reflux
- Achalasia
- Unrepaired hernias of the abdominal wall potentially containing bowel

METABOLIC AND ENDOCRINOLOGICAL

Relative Contraindications: With the exception of diabetes mellitus, states of altered hormonal or metabolic function should be assessed according to their impact on the individual's ability to tolerate the moderate exercise requirement and environmental stress of sport diving. Generally divers with altered hormonal status should be in as near an optimal physiologic state as is possible. It should be noted that obesity predisposes the individual to decompression sickness and is an indicator of poor overall physical fitness.

- Hormonal excess or deficiency
- Obesity
- Renal insufficiency

Absolute Contraindications: The potentially rapid change in level of consciousness associated with hypoglycemia in diabetics on insulin therapy or oral hypoglycemic medications can result in drowning. Diving is therefore contraindicated.

PREGNANCY

Venous gas emboli formed during decompression may result in fetal malformations. Diving is absolutely contraindicated during any stage of pregnancy.

HEMATOLOGICAL

Abnormalities resulting in altered rheological properties may increase the risk of decompression sickness.

Relative Contraindications: Absolute Contraindications:

Sickle cell trait
Acute anemia

Sickle cell disease
Polycythemia
Leukemia

ORTHOPEDIC

Relative impairment in mobility particularly in the small boat environment or ashore with equipment weighing up to 40 pounds must be assessed. The impact of exercise ability is also an important consideration.

Relative Contraindications

- Chronic back pain
- Amputation
- Scoliosis - must also assess impact on pulmonary function
- Aseptic necrosis - possible risk of progression related to adequacy of decompression

BEHAVIORAL HEALTH

Behavioral: The diver's mental capacity and emotional makeup are important to safe diving. The student diver must have sufficient learning abilities to grasp information presented to him by his instructors, be able to safely plan and execute his own dives and react to changes about him in the underwater environment. The student's motivation to learn scuba and his ability to deal with potentially dangerous situations is also crucial to safe diving.

Relative Contraindications:

- Developmental delay
- History of drug or alcohol abuse
- History of previous psychotic episodes

Absolute Contraindications:

- Inappropriate motivation to dive - solely to please spouse or partner, to prove oneself in the face of personal fears
- Claustrophobia and agoraphobia
- Active psychosis or while receiving psychotropic medications
- History of panic disorder
- Drug or alcohol abuse

Appendix D
RESULTS OF THE SOUND MAPPING

The tables below summarize the deviations from the median sound pressure at each of the four test frequencies used in the study. Rows 1-5 correspond to the array positions listed in the Sound Mapping and Acoustic Setup section above. Columns 1-5 correspond to the hydrophone positions 1 through 5. The median was chosen as a robust statistic to compensate for outliers in the data due to the dB scale. Further, the statistics were formed in the amplitude representation, rather than in the dB representation, again to compensate for outliers. As an example of the bias in the dB scale, the three amplitudes, 0.8, 1.0 and 1.2, have a mean of 1.0. Using the dB scale, the respective dB values are -1.9382, 0, and 1.5836. The mean of these values is -0.118 which corresponds to 0.986, different from 1. For small variations about the mean, the bias is not important; however, when larger excursions (0.7 = about 3 dB) the bias is significant.

Table D1: Deviations from median for 600 Hz (mean deviation = -0.17, SD =1.1)

0.53	0.7	0	0.25	-1
1	1.4	0.51	0.6	-0.24
-1.1	-0.69	-1.9	-1.9	-2.9
-0.91	-0.48	-1.4	-1.1	-1.8
1.2	1.3	0.73	0.93	0.18

Table D2: Deviations from median for 1000 Hz (mean deviation = 0.012, SD = 0.86)

0.1	1.2	-0.47	0.5	0.19
0.66	2.2	-0.34	0.32	0.13
-0.95	0	-1.7	-0.79	-1.2
-0.15	0.81	-0.98	-0.5	-0.86
-0.4	1	-0.98	0.66	0.8

Table D3: Deviations from median for 1750 Hz (mean deviation = -0.13, SD = 1.3)

1.4	-1.7	0.23	1.1	-0.8
-0.14	-1.2	-1.9	-1.5	-3.1
0.98	0.72	0.73	1.5	-0.59
0.16	-0.32	0.18	1.1	-2.7
2.8	0.18	-1.1	-2.1	0

Table D4: Deviations from median for 2420 Hz (mean deviation = 0.053, SD = 1.8)

0.65	-2.4	0.2	0.83	-1.1
0.49	-2.8	-1.3	0.37	-0.85
3.2	0	2	3.5	-0.77
2.8	-1.7	-1.7	0.92	-1
-0.71	-2.4	0.54	1.5	-4

The table below summarizes the distribution for mean and standard deviation vs. frequency when the median is chosen at 0 dB. As expected, the spread increases with frequency, as do the outliers.

Table D5: Summary of Tables D1 –D4 showing overall mean and standard deviation by frequency

Frequency	Mean	Sigma	±95%
600	-0.17	1.1	2.2
1000	0.012	0.86	1.72
1750	-0.13	1.3	2.6
2420	0.053	1.8	3.6

Initial placement of the sound projectors was determined by modeling efforts. Final placement of the projectors was determined following preliminary sound mapping at several test placements. The source placement chosen was designed to make the field most uniform at the diver axis in the region of head and thorax. The summary below shows the pressures relative to the median along this axis (array position 1) for the four frequencies for the final projector configuration. The figures in red show the head and thorax region.

Table D6: Summary of the deviation in SPL (dB) relative to the median when the median is chosen as 0 dB for array position 1 (along the long axis of the diver at 1.0 m depth) for each of the test frequencies.

600 Hz	0.53	1	-1.1	-0.91	1.2
1000 Hz	0.1	0.66	-0.95	-0.15	-0.4
1750 Hz	1.4	-0.14	0.98	0.16	2.8
2420 Hz	0.65	0.49	3.2	2.8	-0.71

Appendix E
The computer generated randomized stimulus order matrix

Starting Position	Frequency	SPL
1	2500	154
2	silence	
3	2500	166
4	1000	140
5	1000	166
6	2500	140
7	2500	148
8	1750	140
9	600	148
10	silence	
11	1000	148
12	1750	148
13	600	154
14	1000	154
15	600	163
16	silence	
17	1750	166
18	600	140
19	1750	154

Appendix F

Least Squares linear regression equations for loudness and vibration as a function of SPL for each LFWBS frequency

Loudness ratings (see Figure 7)
Loudness at 600 Hz = 0.13 x SPL – 16.69
Loudness at 1000 Hz = 0.117 x SPL – 14.92
Loudness at 1750 Hz = 0.108 x SPL – 13.31
Loudness at 2420 Hz = 0.115 x SPL – 13.77

Vibration ratings (see Figure 9)
Vibration at 600 Hz = 0.039 x SPL – 5.44
Vibration at 1000 Hz = 0.016 x SPL – 2.09
Vibration at 1750 Hz = 0.013 x SPL – 1.67
Vibration at 2420 Hz = 0.02 x SPL – 2.73

Appendix G
Summary Statistics comparing pre and post dive performance on the ANAM 2000 Tes
Code substitution T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PREMRT	1126.8481	21	205.5243	44.8491
	POSTMRT	1062.7024	21	146.4903	31.9668
Pair 2	PRESD	377.9724	21	152.3333	33.2419
	POSTSD	394.7529	21	145.2910	31.7051
Pair 3	PREACC	93.9776	21	5.6113	1.2245
	POSTACC	95.7667	21	3.7121	.8100
Pair 4	PRETP	51.5281	21	10.6135	2.3161
	POSTTP	54.7148	21	8.0366	1.7537

The following units are used througho

Mean Reaction Time (MRT) = ms
Accuracy (ACC) = % correct
Throughput (TP) = number of correct

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	PREMRT & POSTMRT	21	.817	.000
Pair 2	PRESD & POSTSD	21	.174	.451
Pair 3	PREACC & POSTACC	21	.910	.000
Pair 4	PRETP & POSTTP	21	.846	.000

Paired Samples Test

		Paired Differences					t	df
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper		
Pair 1	PREMRT - POSTMRT	64.1457	120.3916	26.2716	9.3441	118.9473	2.442	
Pair 2	PRESD - POSTSD	-16.7805	191.3500	41.7560	-103.8820	70.3210	-.402	
Pair 3	PREACC - POSTACC	-1.7890	2.7129	.5920	-3.0239	-.5542	-3.022	
Pair 4	PRETP - POSTTP	-3.1867	5.7402	1.2526	-5.7996	-.5738	-2.544	

Code substitution-short delay T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PREMRT	1254.8962	21	337.6896	73.6899
	POSTMRT	1149.0419	21	366.7014	80.0208
Pair 2	PRESD	529.1224	21	382.7996	83.5337
	POSTSD	469.8790	21	497.3355	108.5275
Pair 3	PREACC	89.9467	21	11.9937	2.6172
	POSTACC	91.7981	21	9.7207	2.1212
Pair 4	PRETP	45.9638	21	13.7277	2.9956
	POSTTP	51.7057	21	14.1271	3.0828

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	PREMRT & POSTMRT	21	.505	.020
Pair 2	PRESD & POSTSD	21	-.066	.775
Pair 3	PREACC & POSTACC	21	.528	.014
Pair 4	PRETP & POSTTP	21	.627	.002

Paired Samples Test

		Paired Differences					t	df
					95% Confidence Interval of the Difference			
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper		
Pair 1	PREMRT - POSTMRT	105.8543	351.4598	76.6948	-54.1283	265.8369	1.380	
Pair 2	PRESD - POSTSD	59.2433	647.3986	141.2740	-235.4490	353.9357	.419	
Pair 3	PREACC - POSTACC	-1.8514	10.7337	2.3423	-6.7374	3.0345	-.790	
Pair 4	PRETP - POSTTP	-5.7419	12.0270	2.6245	-11.2165	-.2673	-2.188	

Code substitution long delay T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PREMRT	1312.2219	21	342.4363	74.7257
	POSTMRT	1157.3081	21	337.5796	73.6659
Pair 2	PRESD	592.1095	21	357.3633	77.9831
	POSTSD	383.5186	21	182.2746	39.7756
Pair 3	PREACC	87.0362	21	14.4149	3.1456
	POSTACC	87.8290	21	13.3344	2.9098
Pair 4	PRETP	42.0281	21	14.3514	3.1317
	POSTTP	47.1119	21	14.2319	3.1057

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	PREMRT & POSTMRT	21	.545	.011
Pair 2	PRESD & POSTSD	21	.060	.798
Pair 3	PREACC & POSTACC	21	.551	.010
Pair 4	PRETP & POSTTP	21	.534	.013

Paired Samples Test

		Paired Differences					t	df
					95% Confidence Interval of the Difference			
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper		
Pair 1	PREMRT - POSTMRT	154.9138	324.4986	70.8114	7.2038	302.6238	2.188	
Pair 2	PRESD - POSTSD	208.5910	391.3820	85.4066	30.4360	386.7459	2.442	
Pair 3	PREACC - POSTACC	-.7929	13.1788	2.8758	-6.7918	5.2060	-.276	
Pair 4	PRETP - POSTTP	-5.0838	13.7993	3.0112	-11.3652	1.1975	-1.688	

Simple Reaction Time Dependent T-Test Results.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PREMRT	256.2157	21	30.5741	6.6718
	POSTMRT	244.6448	21	27.6715	6.0384
Pair 2	PRESD	68.3486	21	59.6678	13.0206
	POSTSD	52.4267	21	24.3416	5.3118
Pair 3	PRETHRUP	237.3967	21	28.5963	6.2402
	POSTTP	247.9281	21	25.2259	5.5047

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	PREMRT & POSTMRT	21	.673	.001
Pair 2	PRESD & POSTSD	21	.596	.004
Pair 3	PRETHRUP & POSTTP	21	.682	.001

Paired Samples Test

		Paired Differences					t	df
					95% Confidence Interval of the Difference			
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper		
Pair 1	PREMRT - POSTMRT	11.5710	23.7103	5.1740	.7782	22.3637	2.236	
Pair 2	PRESD - POSTSD	15.9219	49.2163	10.7399	-6.4811	38.3249	1.483	
Pair 3	PRETHRUP - POSTTP	-10.5314	21.6916	4.7335	-20.4053	-.6575	-2.225	

Continuous Performance Test T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PREMRT	515.7233	21	55.7860	12.1735
	POSTMRT	491.9990	21	57.8453	12.6229
Pair 2	PRESD	137.3905	21	30.3171	6.6157
	POSTSD	137.8162	21	31.7585	6.9303
Pair 3	PREACC	96.5033	21	2.0361	.4443
	POSTACC	95.6005	21	3.3150	.7234
Pair 4	PRETHRUP	113.7986	21	12.6470	2.7598
	POSTTP	117.8805	21	12.1525	2.6519

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	PREMRT & POSTMRT	21	.744	.000
Pair 2	PRESD & POSTSD	21	.375	.094
Pair 3	PREACC & POSTACC	21	.514	.017
Pair 4	PRETHRUP & POSTTP	21	.622	.003

Paired Samples Test

		Paired Differences					t	df
					95% Confidence Interval of the Difference			
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper		
Pair 1	PREMRT - POSTMRT	23.7243	40.6863	8.8785	5.2041	42.2445	2.672	
Pair 2	PRESD - POSTSD	-.4257	34.7250	7.5776	-16.2323	15.3809	-.056	
Pair 3	PREACC - POSTACC	.9029	2.8627	.6247	-.4002	2.2059	1.445	
Pair 4	PRETHRUP - POSTTP	-4.0819	10.7936	2.3554	-8.9951	.8313	-1.733	

Matching to Sample T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PREMRT	1174.0171	21	238.3221	52.0061
	POSTMRT	1371.9976	21	453.5160	98.9653
Pair 2	PRESD	360.3633	21	126.8660	27.6844
	POSTSD	530.7629	21	546.5878	119.2752
Pair 3	PREACC	95.8724	21	6.4898	1.4162
	POSTACC	93.9676	21	8.4069	1.8345
Pair 4	PRETP	50.9129	21	11.8797	2.5924
	POSTTP	45.0090	21	14.4242	3.1476

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	PREMRT & POSTMRT	21	.787	.000
Pair 2	PRESD & POSTSD	21	.353	.116
Pair 3	PREACC & POSTACC	21	.091	.694
Pair 4	PRETP & POSTTP	21	.731	.000

Paired Samples Test

		Paired Differences					t	df
					95% Confidence Interval of the Difference			
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper		
Pair 1	PREMRT - POSTMRT	-197.9805	304.0154	66.3416	-336.3666	-59.5943	-2.984	
Pair 2	PRESD - POSTSD	-170.3995	515.6226	112.5181	-405.1081	64.3091	-1.514	
Pair 3	PREACC - POSTACC	1.9048	10.1405	2.2128	-2.7112	6.5207	.861	
Pair 4	PRETP - POSTTP	5.9038	9.9319	2.1673	1.3829	10.4247	2.724	

Math T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PREMRT	2255.1314	21	689.0928	150.3724
	POSTMRT	2116.8210	21	663.8208	144.8576
Pair 2	PRESD	736.2481	21	357.7136	78.0595
	POSTSD	725.7233	21	287.0323	62.6356
Pair 3	PREACC	91.4286	21	7.7690	1.6953
	POSTACC	91.1905	21	8.9310	1.9489
Pair 4	PRETP	26.1486	21	8.6013	1.8770
	POSTTP	27.5690	21	8.1100	1.7697

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	PREMRT & POSTMRT	21	.951	.000
Pair 2	PRESD & POSTSD	21	.655	.001
Pair 3	PREACC & POSTACC	21	.587	.005
Pair 4	PRETP & POSTTP	21	.936	.000

Paired Samples Test

		Paired Differences					t	df
					95% Confidence Interval of the Difference			
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper		
Pair 1	PREMRT - POSTMRT	138.3105	212.6201	46.3975	41.5270	235.0940	2.981	
Pair 2	PRESD - POSTSD	10.5248	275.4163	60.1008	-114.8432	135.8927	.175	
Pair 3	PREACC - POSTACC	.2381	7.6610	1.6718	-3.2491	3.7253	.142	
Pair 4	PRETP - POSTTP	-1.4205	3.0264	.6604	-2.7981	-4.29E-02	-2.151	