COMPARISON OF COGNITIVE AND PSYCHOMOTOR PERFORMANCE ACROSS GENDER IN HYPERBARIC AND SIMULATED HYPERBARIC CONDITIONS

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COMPARISON OF COGNITIVE AND PSYCHOMOTOR PERFORMANCE ACROSS GENDER IN HYPERBARIC AND SIMULATED HYPERBARIC CONDITIONS

by

© Julia M. Jennings, B. Kin.

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Thesis Abstract

In this thesis the effects of nitrogen gas narcosis on cognitive and psychomotor performance were examined with respect to gender. Six male and six female participants were each tested at surface pressures breathing air, in a hyperbaric chamber simulating either a depth of 60ft and or a depth of 165fsw. In a second study participants were tested at a surface pressure of 1 ATmosphere Absolute (ATA) breathing a 30% normoxic nitrous oxide mixture. In study 1 cognition was evaluated using a simple arithmetic test, a modified Stroop test and a number comparison test. These 3 tests of cognition plus a recognition memory test were employed in study 2. Psychomotor performance was evaluated in both studies using a matrices drawing test and a modified Purdue peg-board test. The results illustrated the effects of nitrogen narcosis were not evident for all cognitive tests employed. In both studies, with the exception of the recognition memory test, females performed as well or better than males for these cognitive and psychomotor tests. Females at 1 ATA breathing a 30% normoxic nitrous oxide had significantly lower ($p=0.001$) memory scores than males but this may have been due to a pre-existing difference in the sample. In conclusion, during actual or simulated nitrogen narcosis, the evidence collected supported little effect of gender on cognitive and psychomotor performance during narcosis.

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I would like to thank my supervisor Dr. Matthew White for his wisdom and guidance throughout this challenging and rewarding experience. I would also like to thank Dr. Ken Ledez, Dale Decker, and Craig Reed at the Center for Offshore and Remote Medicine (MEDICOR) for their time and patience without which I would have never completed this project. Next, I would like to thank Lise Petrie for her endless assistance and kindness as well as my friends and fellow graduate students for their support day after day. I would also like to express immense gratitude to those who volunteered their time and effort to take part in this study. Lastly, I would like to thank my boyfriend Chad for his faith and encouragement, my sister Alicia for her compassion during stressful times and also my parents for providing me with the strength and perseverance to reach my goals.

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List of Abbreviations

ATA – Atmospheres Absolute

BI – Bioelectric Impedance

BFC – Body Fat Composition

DEXA – Dual Energy X-ray Absorptiometry

fsw – feet of sea water

HPNS – High Pressure Nervous Syndrome

LTM – Long-Term Memory

N_2O – Nitrous oxide

SCUBA – Self-contained Underwater Breathing Apparatus

STM – Short-Term Memory

List of Definitions

Arithmetic Test – The arithmetic test is used to assess the understanding of basic mathematical relationships and processes. This is a test of basic cognitive ability.

Atmospheres Absolute (ATA) – Defines as the total pressure exerted on an object, by a gas or mixture of gases, at a specific depth or elevation, including normal atmospheric pressure.

Bennett Hand Tool Dexterity Test – Measures eye-hand coordination and manual dexterity in the use of medium sized tools.

Dichotic Listening Tests - Tests for central hearing disorders based on the competing message technique (binaural separation).

Digit Span – This is a subtest of the Wechsler memory scale. The test measures short term auditory memory.

High Pressure Nervous Syndrome – A syndrome of tremors, nausea, dizziness, and decreased motor and mental performance which develops in those who dive deeply (e. g. 1000 ft) usually breathing a mixture of oxygen and helium. Nitrogen is can be added to the oxygen and helium to give trimix that helps alleviate the symptoms of HPNS.

Hyperbaric Chamber - A land-based, high-pressure chamber, which will accommodate humans at varying pressures to simulate depths inside the chamber.

Matrices Test – A test of basic cognitive and psychomotor functioning. It is believed that this task requires flexibility of closure in the task of superimposing the specific pattern on a strong visual field.

Number Comparison Test – The number comparison test is used primarily to measure perceptual speed.

P300 - A late-appearing component of the event-related potential. P stands for positive voltage potential and 300 represents 300 milliseconds post-stimulus. Its amplitude increases with unpredictable, unlikely, or highly significant stimuli and thereby constitutes an index of mental activity.

Paired Associative Learning – Type of human leaning task consisting of one or more pairs of items or elements in which the learner must associate or connect together the two members within each pair. The technique is used for the study of human learning and memory.

Purdue Pegboard Test – Purdue Pegboard Test is used to measure an individual's ability to move hands fingers and arms (gross movement) and to control movement of small objects (finger tip dexterity). The test is used regularly on assembly workers, general factory workers, various industrial positions and vocational rehabilitation.

Recognition Memory Test – Individual is presented with previously presented words or stimuli in the company of other words or stimuli that are new. They are required to differentiate between the items originally presented and new items. The test evaluates recognition memory ability.

Stroop Test –The Stroop test is used to evaluate personality, cognition, stress response, psychiatric disorders, and other psychological phenomena. The test can be used to differentiate normal, non-brain-damaged psychiatric from brain damaged participants. The Stroop Task is a psychological test of our mental vitality and flexibility. The cognitive mechanism used in this task is called inhibition. The challenge is to inhibit or stop one response and do something else.

Wechsler Memory Scale – An individually administered measure of memory for verbal and figural stimuli, memory for meaningful and abstract material, and delayed and immediate recall. It can be used as a diagnostic or screening device as part of a general neuropsychological examination or other clinical examination that requires the assessment of memory functioning.

Chapter 1: Thesis Overview

1.1. Thesis Overview

As Self-Contained Underwater Breathing Apparatus (SCUBA) diving is becoming more popular among males and females in both professional and recreational settings, it is important that divers be aware of any possible gender differences that may be apparent in hyperbaric environments. It is already well established that human physiological, cognitive and psychomotor performance are impaired in hyperbaric environments. After an extensive review of the literature in Chapter 3 (2-6) it was concluded there are virtually no studies examining cognitive and psychomotor changes in female divers in hyperbaric conditions. It was the goal of the two studies in this thesis to gain a better understanding of the possible cognitive and psychomotor effects that occur at depth, as well as to make a comparison of these effects between both male and female participants.

In the first study (Chapter 3), a gender comparison of the cognitive and psychomotor effects of inert gas narcosis was examined in a hyperbaric environment. Participants were tested at the surface breathing air and in a hyperbaric chamber while at simulated depths of 60 fsw and 165 fsw. Cognitive ability was evaluated using a simple arithmetic test, a modified Stroop test and a number comparison test. Psychomotor ability was evaluated using a modified Purdue peg-board test and a matrices drawing test. The results showed that females performed as well or better than males during nitrogen narcosis. It appeared that the experience levels of divers may have blocked a demonstration of the effects of narcosis for some cognitive tests that were employed. Overall, the results of this experiment suggested no gender differences in cognitive or psychomotor ability at simulated depths of 60 fsw and 165 fsw.

In our second study (Chapter 4), a gender comparison of the cognitive and psychomotor tasks was made at surface pressure with nitrous oxide induced narcosis. Participants breathed either air or, to simulate a nitrogen narcosis, a gas mixture of 30% nitrous oxide, 21% oxygen and 49% nitrogen (1). Again cognition was evaluated using a simple arithmetic test, a modified Stroop test and a number comparison test plus the participants completed a recognition memory test. Psychomotor ability was again evaluated using a modified Purdue peg-board test and a matrices drawing test. The results of the experiment showed an effect of Gas Condition in all tests excluding the matrices drawing test; that is a decrease in performance on the tests was seen relative to the same tests in the control condition when subjects breathed air. Excluding the recognition memory test, there was no effect of gender across the test battery. For recognition memory females showed a significantly lower performance relative to males when they were breathing the nitrous oxide gas mixture or air. Therefore, the results of this second study supported the hypothesis that there are no gender differences in cognitive and psychomotor ability at a simulated depth of approximately 165 fsw. With respect to recognition memory, however, it appears that gender differences may be evident for memory during inert gas narcosis. This difference in memory may have been pre-existing as evidenced for means from the air-trials.

Overall, both studies support the idea that cognitive and psychomotor ability are affected during nitrogen narcosis. Our studies suggested that females are not at a greater risk than their male counterparts under these conditions. These studies are only a start of the comparison of male and female divers function at depth. Further research is needed to gain a fuller understanding of any possible differences in cognitive and psychomotor ability across gender. More specifically, future studies should focus on the memory capacity of both male and female divers in hyperbaric conditions.

The thesis is concluded in Chapter 5 where a response to the research hypothesis and testable questions are given.

1.2 Co-Authorship Statement

i) Design and Identification of the Research Proposal

Contributions to the design and identification of the research proposal were made both by Matthew D. White Ph.D and by Julia Jennings, B. Kin.

ii) Practical Aspects of the Research

Contributions to the practical aspects of the research were made by Matthew D. White Ph. D., Julia Jennings B. Kin., Dave Behm Ph. D., Dale Decker. Dr. Ken Ledez, M. D., and Lise Petrie, B. Sc.

iii) Data Analysis

Contributions to the research data analysis were made both by Matthew D. White Ph. D. and by Julia Jennings B. Kin.

iv) Manuscript Preparation

Contributions to the manuscript preparation were made both by Matthew D. White Ph.D and by Julia Jennings B. Kin.

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Chapter 2: Literature Review

2.1 Nitrogen Narcosis

2.1.1 What is Nitrogen Narcosis?

P.B. Bennett (8) reviewed inert gas narcosis and stated that at pressures above 4 ATmospheres Absolute (ATA) or at depths of more than 100 ft, dangerous symptoms of narcosis are apparent. He refers to many early studies of narcosis (9, 30, 38) which reveal that the symptoms of breathing compressed air can include symptoms of intoxication such as, hallucinations, impaired judgment, loss of memory, difficulty assimilating facts and making decisions and having a lively imagination. Later studies (35, 36) revealed similar signs and symptoms of narcosis (8). In addition, Bennett mentions some earlier studies that focused on the cognitive effects of narcosis. Amongst these studies is one which states that at depths of 300 fsw divers breathing compressed air were abnormal mentally and experienced a loss of memory (15). Later research showed that at similar depths divers had trouble assimilating facts and making decisions; this included a reported a 'lapse of consciousness' in the diver in 17 of 58 dives to 330-220 fsw (37). Bennett also makes reference to a study which suggested that mental impairment can occur at depths of only 33-66 fsw (56). A similar study was later repeated by Bennett et al. 1967 (as cited in (8)) and findings showed that the minimal pressure of nitrogen likely to produces symptoms of narcosis is 100 fsw (30m). An additional study (3) mentioned by Bennett emphasized the severity of nitrogen narcosis at pressures greater than 300 fsw. This study also revealed that repeated exposure to breathing compressed air at a depth of 400 fsw resulted in significant acclimatization to the effects of narcosis (8).

Fowler and colleagues (24) investigated the effects of nitrogen narcosis on reaction time and P300 latency and amplitude. Ten participants breathed either air or a non-narcotic heliox mixture of 20% oxygen and 80% helium in a hyperbaric chamber at both 6.5 and 8.3 ATA. By asking the participants to respond to visually-presented male and female names on a computer screen. researchers showed that as predicted, reaction time was slowed by hyperbaric air and this decrease in performance can be attributed to nitrogen narcosis for two reasons. First. the slowed reaction time was shown to be dose related and disappeared on return to the surface in accordance with the typical characteristics of nitrogen narcosis. Second, extraneous conditions such as anxiety, noise, heat or partial pressure of oxygen, were ruled out as causes for the decreased reaction time since this decrease in performance was not observed in the participants breathing the heliox mixture (24).

2.2. Hypotheses of Inert Gas Narcosis

The etiology of inert gas narcosis is thought to be due in part to the narcotic potency of the gas mixture breathed. Inert gas narcosis may be produced by the same mechanisms as general anesthesia with gases or volatile liquids (19). Although it is known that the site of action of anesthetics is in the central nervous system, the exact cellular site is not known (19).

Hesser et al. (34) investigated the roles of nitrogen. oxygen. and carbon dioxide in compressed air narcosis and on manual dexterity. In this study. the goal of the researchers was to determine how nitrogen, oxygen and carbon dioxide differed in their roles in compressed air narcosis. The male participants breathed either air at 1.3ATA, oxygen at 1.7ATA or air at 8.0ATA with varied inspired carbon dioxide fractions. An increase in oxygen pressure to 1.65 ATA or an increase in nitrogen pressure to 6.3ATA at a constant PO_2 level both decreased mental function by 10% but had no effect on psychomotor function. A rise in end-tidal PCO_2 of 10 mmHg caused a decrease of 10% in both mental and psychomotor functions. Overall, it was concluded that all three gases have narcotic properties, and that the mechanism of CO_2 narcosis differs from the mechanism of N_2 and O_2 narcosis. The narcotic effect of CO_2 is thought to be mediated via hydrogen ions as opposed to lipid solubility. Evidence for this was that hydrogen ion concentration correlated with the anesthetic affect of CO_2. It is thought that it is not the CO_2 in the arterial blood that is causing the narcotic effect but the increased concentration of hydrogen ions in the cerebral spinal fluid (34). Reference is also made to an earlier study that illustrated that the ratio of the narcotic potency of carbon dioxide and nitrous oxide is approximately 4:1 (43). The author also states that oxygen and carbon dioxide are approximately 2 and 13 times as soluble in lipids, respectively, as nitrogen (17). This suggests that oxygen and carbon dioxide should be 2 and 13 times as potent as nitrogen. The narcotic potency of carbon dioxide, however, was found to be more than 30 times as narcotic as predicted by the lipid theory (34). The lipid theory of inert gas narcosis is discussed later in this chapter.

2.2.1 Meyer-Overton Hypothesis

In the early 1900's, Meyer and Overton developed a hypothesis stating that there is a parallel between the solubility of an anesthetic in lipid and its narcotic potency. It was concluded that the high narcotic effect of an inert gas is related to its high ratio of solubility in oil versus water. Nitrogen, therefore, is thought to be absorbed very easily into brain lipids causing an increase in performance decrements (46, 52). The view expressed by Meyer & Hopff was that 'all gaseous or volatile substances induce narcosis if they penetrate the cell lipids in a definite molar concentration (0.03 to 0.06 moles drug per kg of membrane) which is characteristic for each type of animal (or type of cell) and is approximately the same for all narcotics (47)'. However, inconsistencies are seen from this generalization. Argon, with a similar oil-water solubility ratio as nitrogen, is about twice as narcotic as nitrogen. This is because argon is twice as soluble in lipids and water (8) than is nitrogen. Further evidence that supports the Meyer-Overton hypothesis is evident in a study examining the sensitivity of mice to electroshock (14). At isonarcotic partial pressures, when each gas exhibits similar pharmacological effects, the inert gas concentration in the lipid is very similar, although the partial pressure of gas required varies (14).

2.2.2 Molecular Weight Hypothesis

It has been noted for some time that the narcotic effect of inert gases increases with their molecular weight. By this view heavier gases diffuse in and out tissues more slowly and as a consequence are more narcotic. This is why a helium/oxygen mixture with a lower net molecular weight than air is used by divers to reach greater depths since there is less narcosis with this mixture (19). For example Hydrogen gas (MW=2) is much less narcotic than Xe (MW=131.3). An inert gas that is an exception to this hypothesis is Neon. Neon gas has a molecular weight of 20 yet its relative narcotic potency much less narcotic than Hydrogen gas despite its greater molecular weight.

2.2.3 Hydrate Formation Hypothesis

This hypothesis suggests that narcosis is related to the stability of the gas hydrates formed in aqueous solution. The hydration of the molecule leads to an ordered structure of water (a crystal) around the anesthetic agent. This hypothesis differs from the lipid hypotheses in that the anesthetic molecule is associated with water molecules rather than lipid molecules. These crystals of gas hydrate are thought to impede the transmission of nerve impulses. It was suggested that clathrates are formed in which the inert gas atoms are held by van der Waals forces in crystalline cages formed by the molecules of a second agent (54). Due to their high dissociation pressures, these hydrates would be unstable under body conditions. These clathrates are thought to cause narcosis by increasing the impedance of nerve tissue. confining electrically charged ions linked with impulse conduction and decreasing metabolism (54). In addition a related hypothesis was suggested that inert gases may increase the area of highly ordered water surrounding a dissolved gas molecule (50). This would result in a decrease in the conductance of brain tissue and the lipid membranes would become stiffened and occluded. An exception to the hydrate formation theory does occur with helium which does not form hydrates and it follows that it has low narcotic potency at depth (19).

2.2.4 Physical Hypotheses

Physical hypotheses are based on the polarizability and volume of the inert gas molecule and are more widely used (8). The physical theories support the concept that the site of action is the cell membrane, which is hydrophobic. Many studies show that membranes are resistant to the effects of anaesthetics and other sites such as the hydrophobic areas of proteins have been targeted. Other studies on the effects of anaesthetics on the enzyme luciferase in certain bacteria suggest that the cellular enzymes may be the site of action and that the anaesthetics compete for binding sites on specific receptors (19). This concept is best illustrated by a study conducted by Franks et al. (27) where researchers were able to show that, over a very wide range of potencies, the activity of the pure soluble protein Firefly Luciferase can be inhibited by 50% at anaesthetic concentrations which are almost identical to those which anaesthetize animals. This is also true for inhaled agents such as halothane, methoxyflurane and chloroform, as well as aliphatic and aromatic alcohols, ketones, ethers and alkanes. The inhibition is shown to be competitive in nature, with anaesthetic molecules competing with substrate (luciferin) molecules for binding to the protein. The mechanism suggested by these researches is that general anaesthetics, despite their chemical and structural diversity, act by competing with endogenous ligands for binding to specific receptors (26).

2.2.5 Critical Volume Hypothesis

The critical volume concept is a physical hypothesis that has been proposed as an extension of the Meyer-Overton hypothesis (39, 40, 49). Narcosis is said to occur when the inert gas is absorbed by the lipid portion of the cell causing it to swell to a size beyond a critical volume. Thus, there is a lipid volume change, which differentiates the anesthetized states. Other factors such as pressure compressibility of the lipid are also thought to affect lipid volume. If pressure is applied, it is thought to counter the expansion of the cell and reverse the anesthetic effect (48). In addition, it has also been suggested that the mechanisms underlying the critical volume hypothesis may also play a role in reducing convulsions associated with high pressure nervous syndrome (HPNS). If convulsions occur as a result of the hydrophobic portion of the cell becoming compressed under pressure then absorption of an inert gas will compensate for this compression and diminish the onset of convulsions (48). There have however been reports that at anesthetic concentrations there is no significant increase in membrane thickness (27). This hypothesis was also quantified (40). Researchers showed that a 0.4% expansion of a membrane was required to effect anesthesia and a 0.4% contraction of the membrane by pressure caused HPNS (8).

2.2.6 Biochemical Hypothesis

Several biochemical hypotheses have been suggested to explain narcosis. The Metabolic Theory of Quastel suggests that anaesthetics interfere with intracellular oxidation by preventing energy transfer from pyruvate to the cytochrome enzyme system

(19). It has also been suggested that the mechanism of narcosis can be attributed to alterations in the function of neurohormone transmitters, such as noradrenaline, serotonin and dopamine (19). The application of pressure reverses the anaesthetic effect of many agents in most species, but not in those which lack glycine as a neurotransmitter. This suggests that the certain actions of anaesthetics may be enhanced by glycine and that pressure antagonizes these actions (19). These hypotheses, however, are not widely held and there is no satisfactory evidence to support biochemical changes at pressures responsible for narcosis (8).

2.2.7 Physical and Biochemical Hypotheses Combined

A hypothesis combining the physical and biochemical theories has been suggested which states that anesthetics interact with the cell membrane blocking ion exchange (44). This, in turn, causes a decrease in oxygen consumption and an increase in energy stores (44). In addition, a study by Mullins in 1954 supported the hypothesis of ion blocking by presenting evidence suggesting that the pores of the cellular membrane are blocked by the inert gas molecules (51).

2.3 Effects of Short Term Exposure To Nitrogen Narcosis

Rogers & Moeller (1989) investigated the effects of brief, repeated 5.5 ATA exposures on susceptibility and adaptation to nitrogen narcosis. Participants were tested with a standing-steadiness task, which measured body sway, at 5.5 ATA and 1.3 ATA on 12 successive days to determine if an initial performance decrement at 5.5 ATA would decrease over time. They showed that standing steadiness was significantly worse at 5.5 ATA than at 1.3 ATA during all twelve testing days. In comparison to previously found results (3) at depths greater than 300 fsw, Rogers & Moeller (1989) concluded that there is little performance adaptation to nitrogen narcosis in response to brief, repetitive exposures to hyperbaric air (58).

2.3.1 Effects of Nitrogen Narcosis

Cognition and Psychomotor Ability During Nitrogen Narcosis

Research investigating cognitive functioning under hyperbaric pressure (4, 5, 7, 8, 12, 16, 22, 45, 55, 62) suggests that various cognitive impairments are seen at several simulated depths.

In 1991, Fothergill and colleagues conducted an experiment investigating the effects of CO_2 and N_2 partial pressures on cognitive and psychomotor performance. This study examined N_2 and CO_2 components of narcosis by comparing the effects of three levels of end-tidal partial pressure of carbon dioxide ($PETCO_2$) at 1 and 6 ATA in 12 male volunteers. Using a modified Stroop test, an arithmetic test, a number comparison test, a figure-copying test, and a Purdue pegboard test, the cognitive performance of the participants was examined at both 1 and 6 ATA. The results of this experiment showed that there was a significant decrease in performance on all tasks at 6 ATA. Nitrogen narcosis produced impairment through decreases in both speed and accuracy of performance on most of the tests (21). Later, Abraini et al (1) investigated the psychomotor and cognitive abilities of experienced divers in a hyperbaric chamber at a high ambient pressure of either air or a mixture of hydrogen-helium-nitrogen-oxygen. Their results suggested that there are motor decrements due to pressure per se and cognitive decrements due to narcotic action. They showed that there was a greater decrease in cognitive performance than in psychomotor performance. With regards to manual dexterity and number ordination, manual dexterity was 2-16% and number ordination was 4-46% below control. Results were compared with lipid solubility theories of narcosis to determine the individual roles of each gas and pressure. They concluded that the cause of the decrease in cognitive ability was due to the narcotic action of the inert gases. The decrease in motor ability was concluded to be a result of the raised pressure (1).

Earlier studies investigating psychomotor performance in a simulated diving environment have indicated that while complex motor ability may be significantly impaired, simple psychomotor performance remains normal (11, 12).

2.4 Memory and Diving

Atkinson & Shiffrin (1968) developed the modal model of memory which suggests that there are three systems for holding information (6). The first is sensory memory which provides temporary storage for information brought by our senses (6). The second is short-term memory (STM) which is sometimes used interchangeably with working memory. STM allows us to retain small amounts of information for brief periods of time. The duration of STM is less than 20 s (6). Studies of STM measure the storage capacity of working memory (23). Research thus far seems to suggest that STM is unaffected by narcosis (23). Nevertheless, studies examining working memory with respect to response time have showed that response will increase as the number of operations required to complete a task increases (25, 61). LTM has been defined as memory which allows us to retain vast amounts of information for long periods of time (6). This memory storage is considered relatively permanent, the capacity is thought to be unlimited, and it has an extremely long duration that can last hours, to months to years (6). The effect of narcosis on LTM has been the focus of most research. Two hypotheses have been proposed as to the mechanisms underlying LTM deficits caused by narcosis (23). The first is that there is a failure to input information into LTM due to some structural deficit (25). Studies supporting this hypothesis used either nitrous oxide or hyperbaric air to show learning deficits that were not improved when manipulations such as a return to the normal state or word cuing were implemented (25, 60). The second hypothesis is that the narcotic effect on memory could be due to a disruption of the processing required to encode information into LTM and retrieve it (2).

Biersner et al. (11) investigated long-term memory while participants breathed either normal air, hyperbaric air that simulated a depth of 65m, or 30% nitrous oxide at surface level. The two tasks that were examined were digit span, forward and backward, as well as simple and difficult paired-associate learning. Results showed that digit span remained normal while breathing nitrous oxide or hyperbaric air, but both narcotic gases significantly impaired simple and difficult paired-associate learning tasks. The results indicated that there is a similarity in the long-term memory effects of both narcotic gases and that the narcotic properties of both gases may be the same (13).

Logue and colleagues (1986) investigated LTM during a simulated 686m deep dive. Using a variety of tests measuring memory function, adaptive function, right hemisphere function, emotional state and allied procedures, cognitive and emotional changes were evaluated while the participants breathed an oxygen-helium-10% nitrogen mixture. Results indicated that at depth participants showed declines in memory as well as adaptive and spatial functions. These declines diminished as participants returned to surface pressures (41).

Free recall and recognition are methods used to study memory for explicit factual information. In a test that measures free recall participants are presented with a list of words and later are asked to recall them in any order. In a recognition test of memory, participants are not asked to produce the material. They are exposed to previously presented word in the company of other words that are new. The participants are then asked to differentiate between the originally presented words and the new words (6).

In a study conducted in 1989 researchers found that at a simulated depth of 36 meters delayed free recall and immediate free recall were significantly impaired while manual dexterity and recognition memory remained normal (55). These results suggest that significant impairment of memory may occur in experienced divers at depth.

A study by Emmerson (1986) was conducted using a test of recognition to determine the effects of environmental context on memory. Research had previously found a positive effect of underwater environment for free recall (28) but not for recognition (29). The researchers aimed to evaluate recognition by presenting both lists of words visually as opposed to previous research (29) that had presented one list orally and the next visually (20). To test recognition in both wet and dry environments a 16-word list was administered at a depth of 20 meters and on the surface in which the participants had 3 min to remember as many of the words as possible. A 5-min delay was interposed between learning and recognition for the purpose of changing environments and to prevent primary learning effects. To help control for disruption, participants that were not required to change environments during the 5-min intermission were asked to perform simple arithmetic calculations. The recognition portion of the test allowed the participants 5 min to circle as many of the original 16 words as possible from a list of 100 words that contained the original list randomly embedded in the list. The results of the study showed that contrary to previous research, there is evidence of an effect of environmental context on recognition in an underwater environment (20). Nitrogen narcosis may have also played a role in decreasing recognition memory at a depth of 20 meters.

2.5 Compressed Air and Nitrous Oxide Compared

The use of nitrous oxide provides a second means to study nitrogen narcosis. The long term effects of repeated exposure to narcosis on subjective and behavioral performance has been investigated (32). Symptoms and performance of 11 volunteers were examined over 5 days of repeated exposure to 30% nitrous oxide at 1ATA. The participants were tested on 5 successive days under two conditions (narcosis and control). Each test session lasted approximately 30 min and a 90 min time lapse was implemented between the two testing conditions. Using an adjective checklist the researchers were able to show clear adaptation to some subjective symptoms of narcosis such as ability to think clearly, dizziness, light-headedness and numbness. With respect to the effects on physical performance, reaction time did not improve over the 5 days relative to the control. The ability to learn a psychomotor task was not affected by narcosis. These findings showed that subjective adaptation can occur without parallel improvements in physical performance. As a result, this research suggests that safety may be compromised in an operational setting that involves repeated exposure to conditions that impact performance and symptoms (32).

An additional study (11) investigated the selective performance effects of nitrous oxide. While breathing 30% nitrous oxide, participants were given several visual tests, the Purdue Pegboard, the Bennett hand Tool Dexterity Test and Wechsler Memory Scale. The results showed that long-term memory, visual function, and fine and gross motor performance was not disrupted while breathing nitrous oxide. Learning and short-term memory, however, were significantly impaired by the narcotic properties of the gas (11).

An exhaustive literature review has uncovered few studies comparing the narcotic effects of breathing compressed air and the narcotic effects of breathing nitrous oxide at surface pressures. A study was conducted (10) which explored the emotional and physiological effects of nitrous oxide and hyperbaric air narcosis. In this experiment, measurements of seven self-reported emotional states (happiness, activity, fear, anger, depression, fatigue, and anxiety) and three physiological variables (heart rate, systolic blood pressure, and diastolic blood pressure) were made among 16 participants under four conditions: 1) All participants breathing air at 1ATA; 2) several days later after breathing either 30% nitrous oxide or air; 3) after a simulated dive to a depth of 57m breathing air in a hyperbaric chamber; and 4) several weeks after hyperbaric exposure with participants breathing air at surface pressure. The experiment concluded that nitrous oxide does not appear to benefit emotional or physiological adaptation to nitrogen narcosis associated with breathing hyperbaric air. It may, in fact, impair emotional adaptation under these experimental conditions (10).

B. Fowler and colleagues (1980) studied the narcotic effects of 35% nitrous oxide and compressed air on memory and auditory perception. In 13 volunteer participants (12 male and 1 female) dichotic listening performance was found to be impaired, but short-term memory was unaffected. The second experiment used the same technique as the first but was controlled for attenuation of sound transmission in the middle ear and showed no impairment in auditory perception or memory. This was accomplished by controlling: 1) pressure increases in the middle ear due to differential solubility of nitrous oxide and nitrogen in the blood and 2) the use of a breathing mixture with a density greater than air. Experiment 3 required the participants to participate in a one-trial free recall of a word list and the results concluded that there were impairments in long-term memory but not short term-memory. These results were compared with those for compressed air and it was concluded that breathing both nitrous oxide and hyperbaric nitrogen show the same effects (25). It can be concluded from these studies that nitrous oxide can be used as a reliable second means of testing the effects of nitrogen narcosis.

2.6 Physical Characteristics of the Female Diver

In 1992, Edmonds, Lowry and Pennefather (19) composed a comprehensive review of women and diving. The article begins by giving a brief history of women divers beginning with the statement that prior to the 1960's, SCUBA diving was primarily a male dominated sport. Female scientists such as Eugenie Clark and Sylvia Earle excited the diving world in the 1960's and 70's. Clark was known as the "shark lady" due to her exceptional skills and abilities in this area and Earle, in 1969, led the first all-women team of aquanauts in the Tektite 2 habitat experiments where they remained under water for two weeks. Also, in 1973, Kati Garner became the first woman to graduate from the US Navy Diving School (19). With respect to SCUBA training, the article demonstrates that physical strength, experience and training are far more important than sexual differentiation. The authors state that the technical, mechanical, and mathematical training of women however, was not as adequate as the men. On the other hand, female instructors tend to be more considerate, conservative and perceptive then male instructors. This allows them to more adequately reassure students and relieve their fears (19). The review also touches on the anatomical differences of men and women divers. It is stated that there are many differences between the sexes that affect their diving performance. The average male differs from the average female with respect to strength, buoyancy, respiratory function, and thermal protection. With respect to muscle strength, the average male is stronger than the average female. Females, on average, are smaller, and have less muscle mass. Women, because of their smaller stature and smaller lung size, require less oxygen and produce less carbon dioxide. As a result, their respiratory minute volume is less, which means that they need to carry less air and therefore can use a smaller SCUBA cylinder. The thermal variations between men and women are also discussed. It is stated that women are better insulated then men because they have more adipose tissue beneath the skin. However, women are less muscular than men so their overall insulation at rest is less (53). Women also have a greater ability to constrict blood flow to the limbs (42). Overall, these factors suggest that women have slower heat loss then men and a natural buoyancy that increases swimming and survival abilities. Overall though, there is an overlap of these characteristics with most men and women, which makes them equivalent to the men on many levels (19).

2.7 Comparison of Male and Female Divers

2.7.1 Decompression Sickness

Very little research has been conducted investigating gender differences in divers (18, 19, 59, 63, 64). Edmonds (19) mentions a study by Susan Bangasser conducted in 1976 that indicated that the incidence of Decompression Sickness (DCS) in females was 3.3 times that of males exposed to the same dive profiles. Also in a study by Hart et al. in 1981 (33) it was concluded that females demonstrated a higher rate of nitrogen loading than males in both subcutaneous and muscular tissue. The Edmonds article also highlights the potential problems of the pregnant diver, maternal effects. and fetal effects (19).

A study by Zwingelberg K.M. and colleagues in 1987 investigated the effects of DCS in women divers (64). This study was designed to show, when comparing women with men, if there is an increased risk of DCS among female divers compared to male divers. The project involved the collection of diving log data from the Naval Diving and Salvage Training Center, Panama City. Fl. Twenty-eight female students were compared to their four hundred eighty-seven male classmates on eight hundred seventy-eight air and helium- dives. The dive depths ranged from 4.6ATA to 10.10 ATA. The total time of the dives ranged from 8 min to 2 h and 6 min. with bottom times of less than 20 min. The results showed that none of the women experienced DCS, while 8 of the men developed symptoms of DCS (64). Robinson (57) disputed Zwingelberg's earlier conclusions on the basis that the researchers misinterpreted the statistical analysis of their data. Robinson's statistical analysis shows that due to the inappropriate sample size used in Zwingelberg's study, it is impossible to accept the conclusion that women are not at an increased risk of DCS (57). Others have reported females have higher indicidences of DCS than males (18, 19, 63)

In a recent study, by St Leger Dowse and colleagues (59), over 10,000 diving questionnaires were distributed to male and female recreational divers in order to make a gender comparison of the diving habits and histories of recreational divers. The results of this study showed that men reported significantly more years of diving experience then their female counterparts. It was also shown that men were more likely to perform more dives per year and to take part in dives requiring staged decompression stops. Results also showed that women logged most of their dives showing more attention to detail then men. With respect to the rate of DCS, the results of this experiment showed that the rate of DCS in men was 2.60 times greater than for women (59).

2.7.2 Nitrogen Narcosis Across Gender

An exhaustive literature review did not uncover any studies comparing male and female cognitive and psychomotor performance changes during air dives or during simulated diving with Nitrous Oxide.

2.7.3 Comparison of Medical Risks during Diving between Males and Females

In 1999, an article was written describing the medical aspects of diving and the differences between male and female divers (31). The authors emphasized that doctors need to be aware of the risks encountered when diving and about gender related differences in these risks. They recognized that muscle mass is more important for insulation from the cold than the amount of fat beneath the skin. It is also mentioned that DCS seems to be slightly greater in women, and this can probably be attributed to the larger fat distribution of women. This suggestion is not supported by more recent results as discussed above (59).

2.8 Research Hypotheses

This thesis will test the null hypotheses that: a) that nitrogen narcosis at different depths (60 fsw and 165 fsw) will have no significantly different effects on cognitive and psychomotor ability due to gender, and b) nitrogen narcosis at 1ATA induced with 30% nitrous oxide, 21% oxygen and balance nitrogen will have no significantly different effects on cognitive and psychomotor ability due to gender.

2.9 Testable Questions

Using an arithmetic test, number comparison test, modified Stroop test, matrices drawing test, modified Purdue Peg Board test, and recognition memory test the questions that will be addressed in this study are:

a) Is there a significant difference in cognitive and psychomotor ability between men and women when diving to a depth of 60 fsw?

b) Is there a significant difference in cognitive and psychomotor ability between men and women when diving to a depth of 165 fsw?

c) Is there a significant difference in cognitive and psychomotor ability between men and women at 1ATA when breathing 30% nitrous oxide, 21% oxygen and nitrogen balance?

d) Is there a significant difference in short-term memory ability between men and women at 1ATA when breathing 30% nitrous oxide, 21% oxygen and nitrogen balance?

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Chapter 3: Comparison of Cognitive and Psychomotor Performance in Males and Females at 0, 60 and 165 feet of Sea Water

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3.1 Abstract

The cognitive and psychomotor effects of inert gas narcosis were examined for any performance differences across Gender. Six male and six female participants were each tested at surface breathing air, in a hyperbaric chamber at a depth of 60 fsw or at a depth of 165 fsw. Cognition was evaluated using a modified Stroop, a simple arithmetic test and a number comparison test. Psychomotor ability was evaluated using a matrices drawing test and a modified Purdue peg-board test. The modified Stroop test, the simple arithmetic test and the matrix test each showed evidence for an effect of Depth independent of Gender, whereas the number comparison test showed no effect of Depth. The results of the experiment showed little evidence to suggest an effect of Gender across the test battery. The results of this experiment support no gender differences in cognitive or psychomotor ability at simulated depths of 60 fsw and 165 fsw.

Keywords: cognition, diving, gender, hyperbaric, inert gas narcosis, psychomotor

3.2 Introduction

There are numerous deleterious effects of increased pressure on the human body during diving (5, 14). One negative consequence of diving is that divers may experience a condition called nitrogen narcosis (20). Symptoms of nitrogen narcosis include emotional and psychological declines (20), impaired auditory perception (16), and slowed in reaction time (15). As the diver goes deeper, the symptoms increase in severity and when the diver ascends the symptoms terminate with no after effects (5). Very little research has been conducted examining the differences in susceptibility to nitrogen narcosis between male and female divers. This is probably since sport and commercial diving were essentially male-dominated activities prior to the 1960's (10). An exhaustive literature review has not uncovered any studies examining the cognitive effects of nitrogen narcosis on females compared to males.

Meyer and Overton hypothesized (22) that an increased oil-water partition coefficient is proportional to an increased narcotic potency of a gas. Higher levels of adiposity might be associated with a greater "loading" of nitrogen and as a result, females may have a greater predisposition to nitrogen narcosis. This view may be unwarranted since the nitrogen narcosis acts on central nervous system tissues. However, some studies supporting this view show females may have a greater disposition to DCS due presumably due to greater loading of nitrogen onto their tissues (10, 30).

In this study, using a hyperbaric chamber to simulate depth, we examined the effects of nitrogen narcosis on cognitive and psychomotor performance of both male and female divers and non-divers.

3.3 Materials and Methods

3.3.1 Participants

Six healthy male volunteers and six healthy female volunteers between the ages of 22 and 45 from the university population participated in this study.

All 12 of the participants were given a questionnaire to determine their diving experience in water and in hyperbaric conditions before volunteering for the present study. The participants all received a comprehensive medical exam and clearance before participating in the study. All participants were given complete confidentiality as well as information and instructions regarding the experimentation. Each participant also signed an informed consent prior to participation. The set of experiments were given ethical clearance by the Memorial University Human Investigations Committee and the Dalhousie University Human Research Ethics Board. This research conformed with the Helsinki declaration. Participant selection was made using a power calculation based on previous results (12) with an α level of 0.05 and a β value of 0.8. The participants' characteristics appear in Table 3-1.

3.3.2 Instrumentation

The experiment was conducted in a dry hyperbaric chamber at the Center for Offshore and Remote Medicine (MEDICOR) facility at the Memorial University of

Newfoundland Health Science Center. This facility permitted simulation of the pressure effects of diving to be conducted within the relative safety of a controlled laboratory setting, thereby reducing some of the potential risks associated with hyperbaric exposure.

3.3.3 Cognitive and Psychomotor Tests

Other equipment needed for the research included, approximately five #2 pencils, a stopwatch, and 5 different cognitive and psychomotor tests. The 5 cognitive tests used were: a modified Stroop test. an arithmetic test, a number comparison test, a figure-copying test, and a Purdue pegboard test. These tests have been employed and validated in previous studies (12).

Modified Stroop Test

This test consisted of the words red, blue, yellow green and black printed on a page, followed by 10 letters. The color name was printed either in its own color or in a different color than the word. If the color was printed in its own color the participant would cross out the succeeding vowels, otherwise consonants from the same adjacent list of 10 letters were crossed out. Overall performance on the test was calculated according to the number attempted. the number correct, and the number of errors within a time period of one minute. This test is considered a measure of stress sensitivity in decision making (28).

Arithmetic Test

The arithmetic test was made up of 48 different arithmetic problems, each consisting of adding or subtracting the result of one-digit by one-digit multiplication from a two-digit number, such as 37 + 6 x 8 or 31 - 8 x 5. The participants were instructed to multiply first, and then to add or subtract, and were asked to solve as many problems as possible in two minutes. This test gave a combined measure of speed and accuracy. They were also instructed that a question skipped or missed would be regarded as incorrect. Participants were instructed to complete the problems in the order presented. In addition, participants were instructed to begin at the upper left hand corner of the test at #1 and proceed down the left column and then to the top of the right hand column at #25. The scores recorded consisted of the number of problems attempted as well as the number of correctly and incorrectly solved problems. A missed problem counted as an error, and lowered the score of a participant who answered only the easy questions. A partially answered problem was not counted as an attempted problem. All of the arithmetic tests were timed with a stopwatch. A single score sensitive to both speed and accuracy was then computed using the formula:

$$\text{SCORE} = \frac{(\text{Number correct x 2})}{(\text{Number attempted + 48})} \text{ X } 100$$

To score 100% the participant needed to complete all 48 problems correctly within 2 minutes. To obtain a good score the participant was required to work fast and accurately.

e.g. 24/26 gives a score of 48/74 x 100 = 65%

Number Comparison Test

This test required participants to examine pairs of 6 digit numbers and indicate whether the numbers in each pair were the same or different. The performance was scored on the number marked correctly, the number marked incorrectly, and the total number attempted in a time period of 45 s. This test measures perceptual speed (11). A single score sensitive to both speed and accuracy was then computed using the formula:

$$\text{SCORE} = \frac{(\text{Number correct x 2})}{(\text{Number attempted + 48})} \quad \text{X 100}$$

To score 100% the participant must complete all number comparisons correctly within the 45-s period. To obtain a good score the participant is required to work fast and accurately.

e.g. 24/26 gives a score of 48/74 x 100 = 65%

Matrices Drawing Test

Each item consisted of a four-line geometric configuration and a square matrix of dots. The task was to replicate as close as possible the figure onto the dots. This task requires flexibility of closure in the act of superimposing the particular shape on a strong visual field (11). Participants were asked to work as accurately and as fast as possible. The score was the number of correctly copied patterns, or portions of patterns, in a time period of 2 min. In addition, the number or portion of patterns attempted, as well as errors, were recorded (12).

Modified Purdue Pegboard Test

For this task, participant used both hands at the same time. They were asked to assemble a series of pins, collars, and washers in the order of, for one assembly, a pin, a washer, a collar, and a washer. The score recorded was the number of individual parts assembled in 1 minute. This task measures fine manual dexterity (26).

3.3.4 Body Composition Tests

Each participant had three separate tests to analyze their body composition. The three tests used were skinfold test, bioelectric impedance test, and Dual Emission X-ray Absorptometry (DEXA) analysis. These values appear in Table 3-1.

Skinfolds

The skinfold test was completed using a Harpenden Skinfold Caliper. The participant's height, weight and date of birth were recorded before the test. The participant was asked to relax during the test to aid in manipulation of the skinfold. Skinfolds were raised by the measurer's fingers at the selected sight. The measurer grasped the folds with the index finger and thumb of the left hand. The caliper pressure plates were applied 1 cm below the edge of the grasping fingers. The caliper was always applied at a right angle to the fold and distal to the pinching fingers. Measurements were read after 2 s of applied pressure. Skinfolds were measured at 8 different sights: triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, medial calf. Each skinfold was completed once before repeating the procedure a second or third time. For each skinfold site, two trials were required to yield results within 5% or the median value was recorded. A sum of the 8 skinfold sites was recorded.

Bioelectric Impedance

The subject's adiposities were estimated with a bioelectric impedance monitor (Tanita Model TBF521, Tokyo, Japan).

DEXA Analysis

The DEXA analysis was conducted on each participant in the Nuclear Medicine department of the Memorial University Health Science Centre. The test required approximately 20 minutes of the participant's time. The test involved the participant lying still in a supine position and it was essential that the individual being tested wear no metal during the testing. The DEXA machine slowly scanned the entire body recording accurately the individual's body composition. A computer record of the results was obtained.

3.3.5 Protocol

Once selected, each participant completed a pre-dive test session. The participants conducted in a minimum of 5 trials of each of the 4 cognitive tests and 1 psychomotor test or until there was a plateau in performance. The control value for the subsequent analyses was the average of a minimum of 3 trials once a plateau in performance had been achieved. In all training and dives the cognitive and psychomotor tests were presented in a random order. As required by the Human Investigations Committee at Memorial University the order of the dives was 60 fsw followed by the 165 fsw dive.

Dive to 60 fsw.

Each participant first participated in a single 60 fsw hyperbaric dive. The participants had a bottom time of 20 min in which they completed all cognitive tests. An additional 1-minute was needed for compression as well as decompression before and after the 20 minute bottom time.

Dive to 165 fsw.

In a second experiment, the same conditions and tests were applied to the same participants who participated in the first experiment at 165 fsw. The divers again had a 20 min bottom time to complete the five tests. This experiment required an additional 67 minutes for decompression following the DCIEM protocol for 180 feet (Fig. 3-1).

3.3.6 Statistical Analysis

The test results obtained at pressure were then compared with the surface control values, using using a split-plot two-way ANOVA. The repeated measures factor was Depth (Levels: 0ft, 65ft, 165ft) and the non-repeated measures factor was Gender (Levels: male, female). In the ANOVA models degrees of freedom for Depth were 2 and for Gender were 1. Post hoc tests employed were orthogonal contrasts within a gender across levels of Depth and one-way ANOVAs between the males and females at each level of Depth. The results were considered significant at a level of 0.05. The statistical software package employed was SuperANOVA (version 1.11, Abacus Concepts, CA, USA).

3.4 Results

The comparison across gender for age and anthropometry (Table 3-1) indicated males were of tended to be of the same age (p=0.06) but were significantly heavier (p<0.001) and taller (p<0.01) than the females. Body composition analyses indicated that for both bioelectric impedance (p<0.01) and the DEXA method (p<0.05) the females had significantly greater levels of adiposity. The skinfold result showed no difference across gender.

The modified Stroop test results are given in Figure 3-2 at the surface and for hyperbaric dives to 60 and 165 fsw. No differences were evident between Gender for the number of Stroop test lines attempted or correct letters at the surface pressures. There was a trend for a significant main effect for Gender (F=4.6, p=0.08) but not a main effect for Depth (F=0.5, p=0.61) for the number of correct responses. This trend for Gender was explained by significant differences at 60 fsw (p=0.003) and at 165 fsw (p=0.009) when females scored significantly higher than males for the number of correct responses. Likewise for the number attempted at 60 fsw (p=0.03) and at 165 fsw (p=0.009) females had significantly higher scores for the number attempted than did the males (Fig. 3-2), No interactions between Gender and Depth were evident for the number of attempted or correct letters in the Stroop test.

Arithmetic test results are given in Figure 3-3. For the arithmetic test number correct there was no main effect of Gender (F=0.63, p=0.46) but there was a main effect of Depth (F=8.2, p=0.008). For the number attempted and for the number correct at the surface, there were no significant differences across Gender. Females performed significantly better than males at 60 fsw ($p=0.02$) by giving more correct responses. The main effect of Depth was explained by a significantly lower ($p=0.007$) mean number of correct responses at 165 fsw of 11.0 ± 1.8 relative to the number correct responses (with values pooled across Gender) at either 0 fsw (14.9 ± 1.8) or at 60 fsw (15.2 ± 1.9). No interactions between Gender and Depth were evident for the arithmetic test.

Figure 3-4, number-comparison results, showed no main effects of Gender ($F=1.7$, $p=0.25$) or Depth ($F=1.5$, $p=0.28$) for the number attempted. For the number attempted and for the number correct at the surface, there were no significant differences across Gender. Females attempted more questions than males at 60 fsw ($p=0.02$) and showed a trend to attempt more comparisons at 165 fsw ($p=0.09$). For the number correct responses there was no main effect of Gender ($F=1.4$, $p=0.28$) or Depth ($F=1.1$, $p=0.36$). However, females outperformed the males at 60 fsw ($p=0.03$). No interactions between Gender and Depth were evident for the number-comparison test.

Matrices drawing test results are given in Figure 3-5. There was no main effect of Gender ($F=0.72$, $p=0.44$) but a significant main effect of Depth ($F=17.5$, $p=0.0005$) for the number attempted. The effect of Depth for the number attempted was explained by progressively higher scores (where a higher score is a poorer score) at 165 fsw (184.8 ± 15.1) relative to that at 60 fsw (169.1 ± 9.3) and relative to that at 0 fsw (141.2 ± 10.6). For the number of correctly drawn matrices there was no main effect of

Gender ($F=1.8$, $p=0.24$) but a significant main effect of Depth ($F=20.9$, $p=0.0003$). Despite no effect of Gender, females tended to score better at 0 fsw ($p=0.09$), at 60 fsw ($p=0.02$) and at 165 fsw ($p=0.06$) than males for the number of correctly drawn matrices. The main effect of Depth for the number of correctly drawn matrices was explained by progressively higher scores (where a higher score is a poorer score) at 165 fsw (209.8 ± 15.5) relative to that at 60 fsw (184.0 ± 13.0) and relative to that at 0 fsw (160.3 ± 13.6). No interactions between Gender and Depth were evident for the matrix drawing test.

The modified Purdue pegboard results are given in Figure 3-6. Results showed a trend for a main effect of Gender ($F=4.4$, $p=0.09$) and no main effect for Depth ($F=0.14$, $p=0.14$) for the number of completed assemblies. The trend for Gender was explained by females completing significantly more assemblies than males at 0 fsw ($p=0.01$) and at 165 fsw ($p=0.01$). There was a trend for a difference across gender at 60 fsw ($p=0.05$). There was no interaction between Gender and Depth for the Purdue pegboard test.

3.5 Discussion

The results of this study indicate that cognitive and psychomotor performance, based on arithmetic and matrices drawing test results, is significantly diminished in comparison to surface values when participants were tested at a simulated depth of 165ft in a hyperbaric chamber. The results, however, showed no indication of diminished cognitive performance on either the modified-Stroop test or the number comparison test as a function of depth. This suggests the 4 cognitive tests were only partially successful as instruments to measure impairments in cognitive abilities during diving.

Females despite having significantly higher levels of adiposity than males (Table 3-1) tended to score the same as males at the surface and better than males at 60 and 165 fsw on the modified Stroop test (Fig. 3-2). For the arithmetic test (Fig 3-3) and the number comparison (Fig. 3-4) tests there was little indication of gender differences. For the matrices drawing test, that measured cognitive and psychomotor ability, showed a significant effect of Depth irrespective of Gender (Fig. 3-5). Although there was no main effect of Gender for the matrices drawing test, females significantly outperformed males at 60 fsw (Fig. 3-5). For the modified Purdue Pegboard test, there was a trend for Gender that was explained by the females scoring significantly better than the males at 0 and 165 fsw (Fig. 3-6). This is despite that there does not appear to be a gender difference for manual dexterity tests such as the Purdue pegboard test (19). The results support the hypothesis of little if any Gender differences for cognitive tests in hyperbaric conditions that induced narcosis. Overall for psychomotor performance, females performed as well or better than males.

Our study showed some dissimilar results to those found by Fothergill and colleagues (12) who examined cognitive and psychomotor ability at 6 ATA. Fothergill and colleagues examined both the N_2 and CO_2 components of narcosis by comparing the effects of three levels of $P_{ET}CO_2$ at 1 and 6 atmospheres of pressure. In their study, performance was evaluated using similar tests including a modified Stroop test, an arithmetic test, a number comparison test, a figure-copying test, and the Purdue pegboard test. The results obtain by Fothergill et. al. (12) showed significant decreases in performance on all tasks at 6 ATA. The decrements in performance seen in Fothergill's study were partly attributed to a high CO_2 tension at 1 ATM which caused further decreases in performance at 6 ATM ($p < 0.05$). It was concluded that at a high $P_{ET}CO_2$, deficits were due to a slowing of performance, not a disruption of the accuracy of processing. On the contrary, nitrogen narcosis produced significant impairment through both decreases in the speed and accuracy of processing on the majority of performance tests. Overall, it was concluded that $P_{ET}CO_2$ and P_IN_2 have an additive effect on decreasing cognitive and psychomotor ability at depth. Our results showed significant decreases in accuracy due to the effects of nitrogen narcosis at 6 ATA on only the arithmetic and matrices drawing tests. No decrements in speed (i.e. number completed) were seen on any of our examinations except the matrices drawing test which showed a significant main effect of Depth for the number of attempted matrices ($F=17.5$, $p=0.005$).

It is of note the decrements at depth when observed in the current study were similar across gender and in magnitude to those observed by Fothergill et al (12) despite difference in body composition between males and females (Table 3-1).

With respect to our tests of psychomotor ability, our results were similar to those found in previous studies (1, 6) in that there are greater decreases in cognitive performance than in psychomotor performance at depth. In the study by Biersner et. al. in 1972 (7) researchers investigated the performance effects of nitrous oxide while breathing 30% nitrous oxide. The results showed that fine and gross motor performance was not disrupted while simulating depth by breathing nitrous oxide (7). In 1978 however, Biersner et. al. (8) were able to show that complex psychomotor performance was impaired significantly during narcosis, while tests of simple psychomotor performance, like those used in our study, remained essentially normal (8). In the study by Abraini et. al. (1) psychomotor and cognitive abilities were investigated during experiments at high ambient pressure of either air or hydrogen-helium-nitrogen-oxygen mixtures. Decrements in psychomotor ability were not as large as decrements in cognitive ability (1). None of the previously mentioned studies investigated cognitive or psychomotor effects on female participants therefore no reasonable comparison can be made with respect to our female results. As depth does not seem to affect psychomotor ability, the superior performance by our female participants on the Purdue peg-board test and matrices drawing test, may be attributed to a smaller hand and finger size than for males. This would make it easier to grasp the small assembly pieces on the pegboard and potentially improve their drawing abilities.

It is difficult to state why no effect of Depth was seen for either the modified Stroop test or the number comparisons test among male and female participants. Previous research investigating cognitive functioning under hyperbaric pressure (2-5, 8, 9, 12, 13, 21, 25, 29) suggests that various cognitive impairments are seen at several simulated depths using a variety of test instruments. Many studies have used similar and dissimilar tools to those used in our study to evaluate cognitive performance. The test battery used by Fothergill and colleagues (12) was very similar to that used in our study, as discussed above. Banks et. al., (3) studied the effects of different high-pressure air environments on human binocular visual recognition time as a function of cognition. Results indicated that recognition time increases as a function of increased pressure (3). Simple and complex psychomotor performance were evaluated by Biersner and colleagues in 1978 (8) using a variety of tools. The results of that study suggested that complex, but not simple, psychomotor performance can be significantly reduced at depth (8). Tests of cognitive function and manual dexterity were examined by Philip et. al. in 1989 (25) using immediate and delayed free recall of words, recognition of previously presented words, number identification, and a forceps pickup of ball bearings. Results of this experiment showed that delayed free recall and immediate free recall were significantly impaired, whereas manual dexterity and recognition memory were not (25). The test of manual dexterity used in this experiment, forceps pickup of ball bearings, may be a more useful tool for examining psychomotor skills between males and females. The use of forceps might eliminate the possibility that the females in our study outperformed the males in our peg-board test due to their smaller hand size. Rogers & Moeller (27) investigated cognition as function of balance and coordination. In this study a standing-steadiness task, which measured body sway, was used to evaluated impairment over time at 5.5 ATA and 1.3 ATA (27). Results indicated after an initial increase in sway at depth was evident with no improvement over 12 successive diving days; this is another possible size independent test to compare gender performance at depth. It is clear that many studies using cognitive and psychomotor measurement tools similar and dissimilar to those used in our study have been useful in demonstrating the impairments that occur at depth. To make further comparisons between Gender with respect to cognition at depth, future studies may want to include some additional functions of cognition such as memory and balance and coordination skills.

As demonstrated in this study and previous studies, cognitive impairment does exist at depths greater than 60 feet below sea level. The proposed mechanisms for this phenomenon are numerous. Inert gas narcosis may be produced by the same mechanisms as general anesthesia with the narcotic properties of gases or volatile liquids acting on the central nervous system (10). Several different hypotheses have been formed to explain the possible mechanisms of narcosis. The Meyer and Overton hypothesis states that there is a parallel between the solubility of an anesthetic in lipid and its narcotic potency (22). The molecular weight theory suggests that the narcotic effect of inert gases increases with their molecular weight, therefore nitrogen with a molecular weight of 28 would be quite potent (10). The hydrate formation hypothesis suggests that narcosis is related to the stability of the gas hydrates formed in aqueous solution. Contrary to the lipid theory, this theory suggests that the anesthetic molecule is associated with water molecules rather than lipid molecules (24). In addition to these theories there are also some physical theories based on the polarizability and volume of the inert gas molecule as well as some biochemical hypothesis that have been used to explain the mechanisms of narcosis. As evident by some of these hypothesis, it has been suggested that females, with a higher average percent body fat are more susceptible to the effects of nitrogen narcosis. A study by Hart el. al. demonstrated that females have a higher rate of nitrogen loading than males in both subcutaneous and muscular tissue (18). In contrast, recent studies (17, 23) suggest females recover faster than males from anesthesia suggesting nitrogen would offload from their tissues more quickly than males. Overall the results of our gender comparison study show no evidence that at depth females are at a higher risk for developing cognitive impairments as opposed to their male counterparts. This was despite that females had significantly higher levels of adiposity than males (Table 3-1)

3.6 Conclusions

Overall, this study has indicated that, under these conditions, there are few differences between genders with respect to cognitive and psychomotor ability. No significant main effects in cognitive ability between men and women were found. When diving to a depth of 60 fsw females scored as well or better than males on the cognitive and psychomotor tests. With the exception of the Stroop test, no significant difference in cognitive ability between men and women was found when diving to a depth of 165 fsw. With respect to the practical implications of this study, women can be considered equal or better to their male counterparts when it comes to cognitive ability during deep sea diving. As it stands, few women today are employed as commercial divers. This may be due to the ongoing assumption that females are physically or cognitively outperformed by males at depth. The results of this study provide evidence contrary to those beliefs.

3.7 Acknowledgements

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Table 3-1. Participant profiles for females (a) and for males (b) tested for cognitive and psychomotor skills in a hyperbaric chamber with the participant breathing air at the surface or breathing compressed air at either 60 or 165 feet of sea-water. Values in the table are mean ± the standard error of the mean (SE). (Bioelectric Impedance (BI): Dual Energy X-ray Absorptiometry (DEXA), (NS= Non Significant, * $p<0.05$, † $p<0.01$, ‡$p<0.001$).

(a)

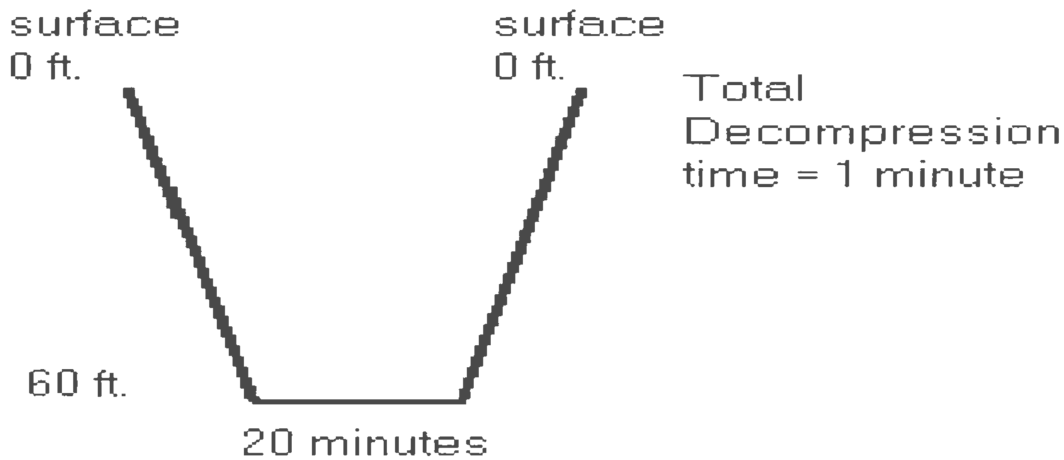
Gender	Age (y)	Height (cm)	Weight (kg)	BI Adult (Fat %)	BI Athlete (Fat %)	∑ Skinfolds (mm)	DEXA (% Fat)
F	22	156.0	50.9	29.5	24.5	141.8	32.8
F	25	161.5	67.9	32.0	23.5	119.8	26.9
F	24	164.0	65.3	34.5	26.5	145.4	30.6
F	27	167.5	68.3	39.5	30.5	139.0	34.8
F	26	164.0	58.3	29.0	20.5	119.0	29.7
F	35	166.5	50.4	25.0	17.0	62.8	18.2
Mean	27	163.3	60.2	31.6	23.8	121.3	28.8
SE	2	1.7	3.4	2.0	1.9	12.6	2.4

(b)

Gender	Age (y)	Height (cm)	Weight (kg)	BI Adult (Fat %)	BI Athlete (Fat %)	∑ Skinfolds (mm)	DEXA (% Fat)
M	43	172.0	73.6	20.5	13.5	123.4	23.1
M	45	179.5	101.5	28.0	17.0	103.9	20.1
M	25	178.5	86.7	24.5	16.0	85.2	19.7
M	38	187.0	91.3	25.0	17.5	156.0	23.6
M	48	173.0	72.6	19.0	12.0	117.0	25.8
M	22	173.0	67.0	18.0	15.0	88.6	22.3
Mean	37^{NS}	$179.0^{‡}$	$83.5^{†}$	$21.9^{‡}$	$13.9^{‡}$	109.3^{NS}	21.1^{*}
SE	4	2.4	4.8	2.0	1.6	12.4	1.6

Figure 3-1. Dive profiles for 60 (a) and for 165 (b) feet of sea-water dives in a hyperbaric chamber with participants breathing compressed air.

(a)



(b)

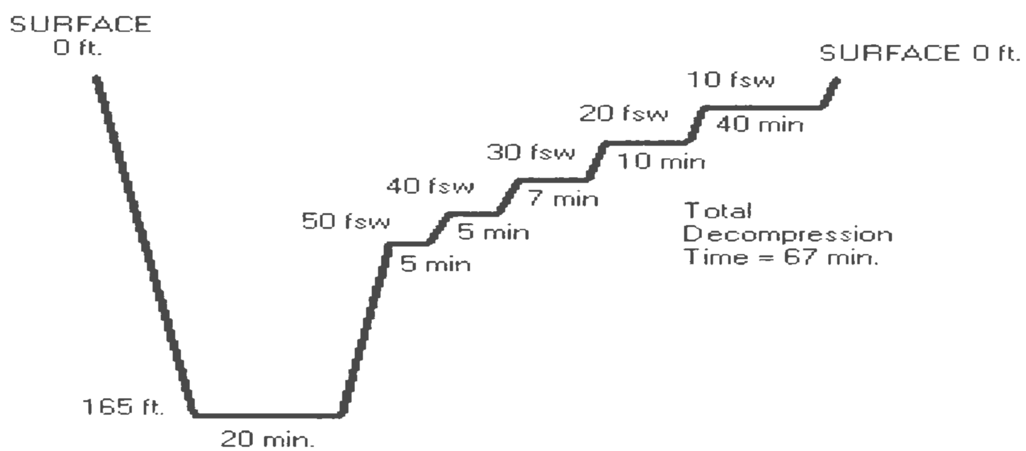


Figure 3-2. Modified Stroop Test- Scores for males and females in a hyperbaric chamber at depths of (a) 0, (b) 60 and (c) 165 feet of sea-water in a hyperbaric chamber. Bars indicate the mean response observed and error bars indicate standard error of the mean (NS= Non Significant, * p<0.05, †p<0.01, ‡p<0.001).

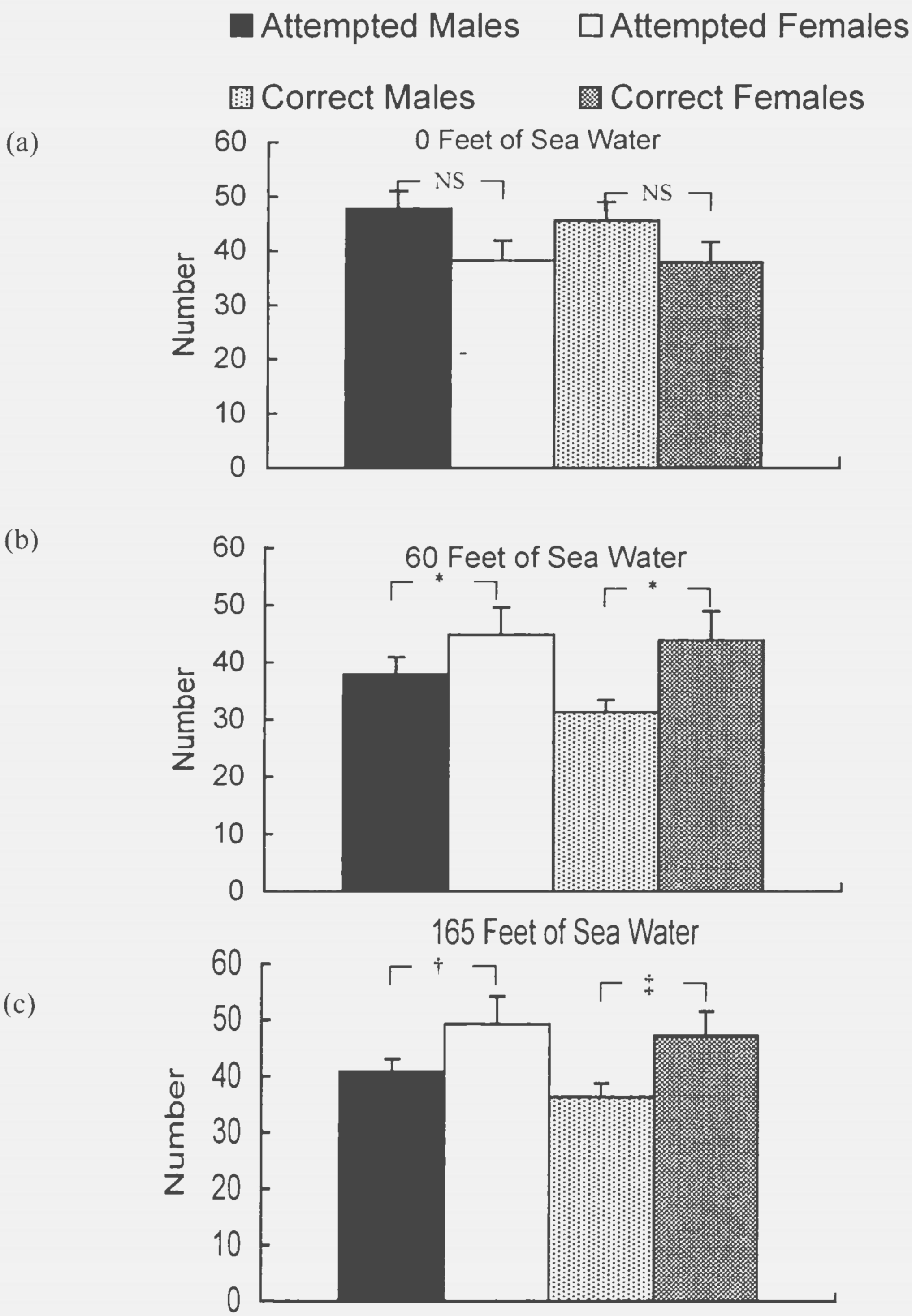


Figure 3-3. Arithmetic test scores for number attempted and number correct for males and females at depths of (a) 0, (b) 60 and (c) 165 feet of sea-water in a hyperbaric chamber. Bars indicate the mean response observed and error bars indicate standard error of the mean (NS= Non Significant, * $p<0.05$, $^{\dagger}p<0.01$, $^{\ddagger}p<0.001$).

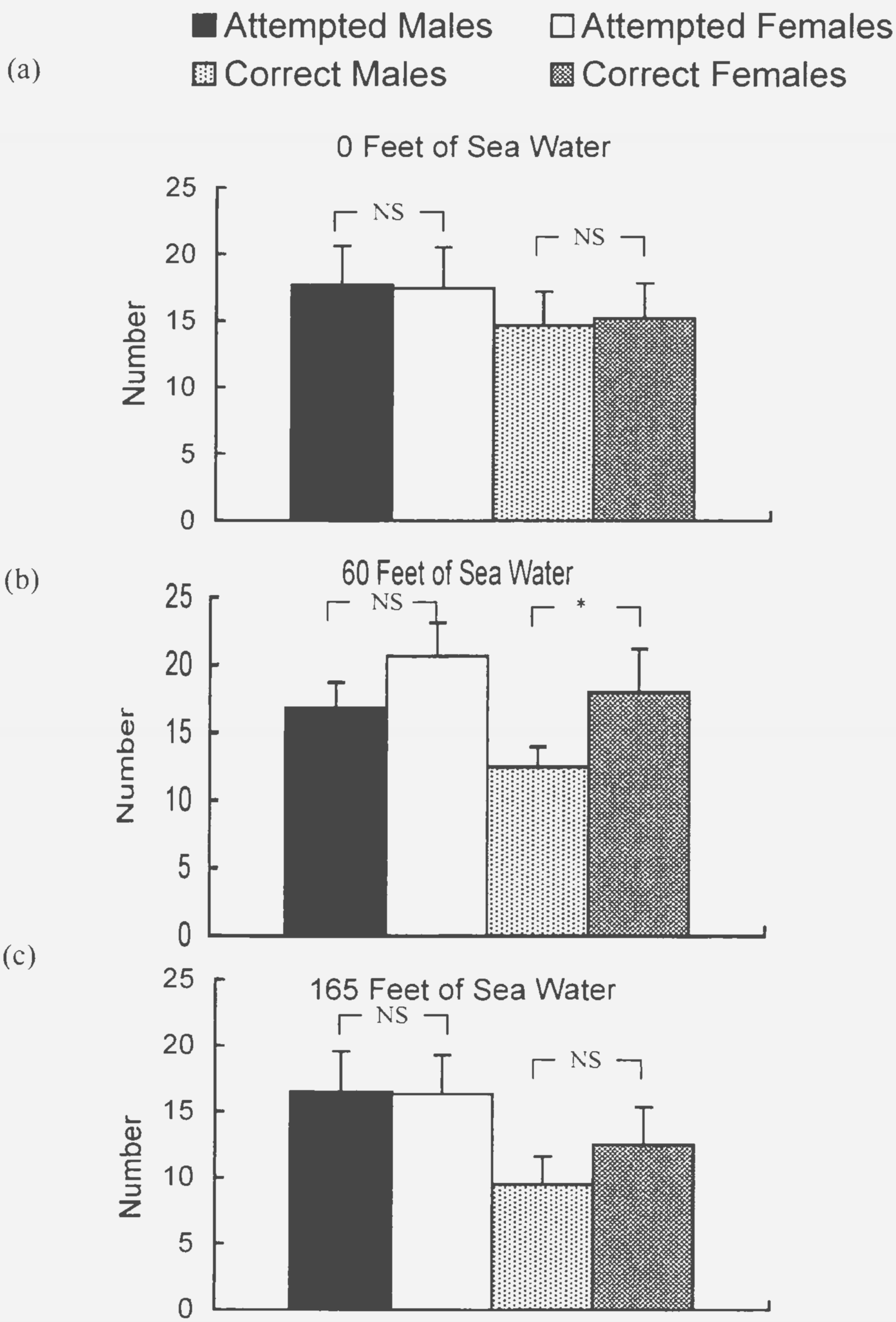


Figure 3-4. Number comparison scores for number attempted and number correct for males and females at depths of (a) 0, (b) 60 and (c) 165 feet of sea-water in a hyperbaric chamber. Bars indicate the mean response observed and error bars indicate standard error of the mean (NS= Non Significant, * $p<0.05$, $^{\dagger}p<0.01$, $^{\ddagger}p<0.001$).

(a)

(b)

(c)

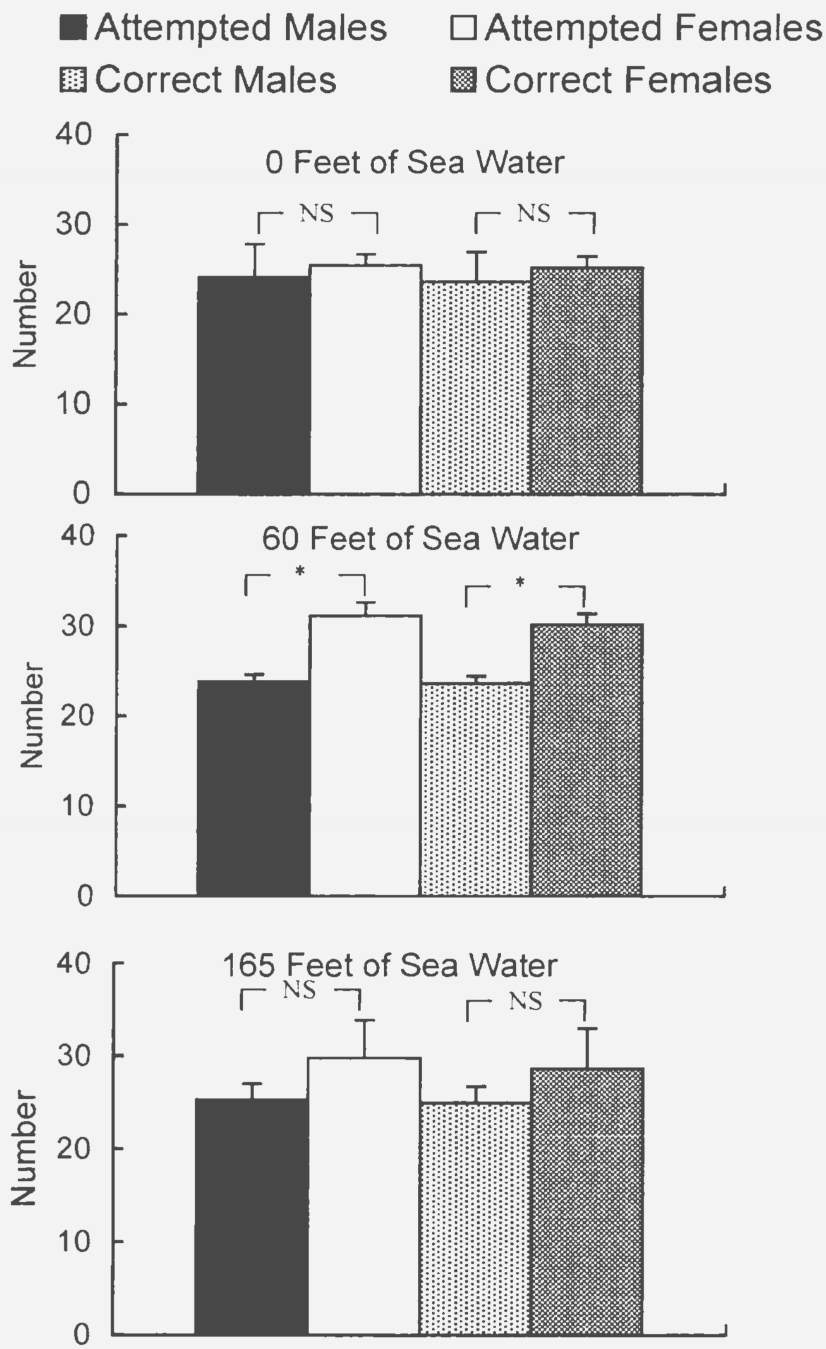


Figure 3-5. Matrices Drawing Test scores for number attempted and number correct for males and females at depths of (a) 0, (b) 60 and (c) 165 feet of sea-water in a hyperbaric chamber. Bars indicate the mean response and error bars indicate standard error of the mean (NS= Non Significant, * $p<0.05$, $^{+}p<0.01$, $^{‡}p<0.001$).

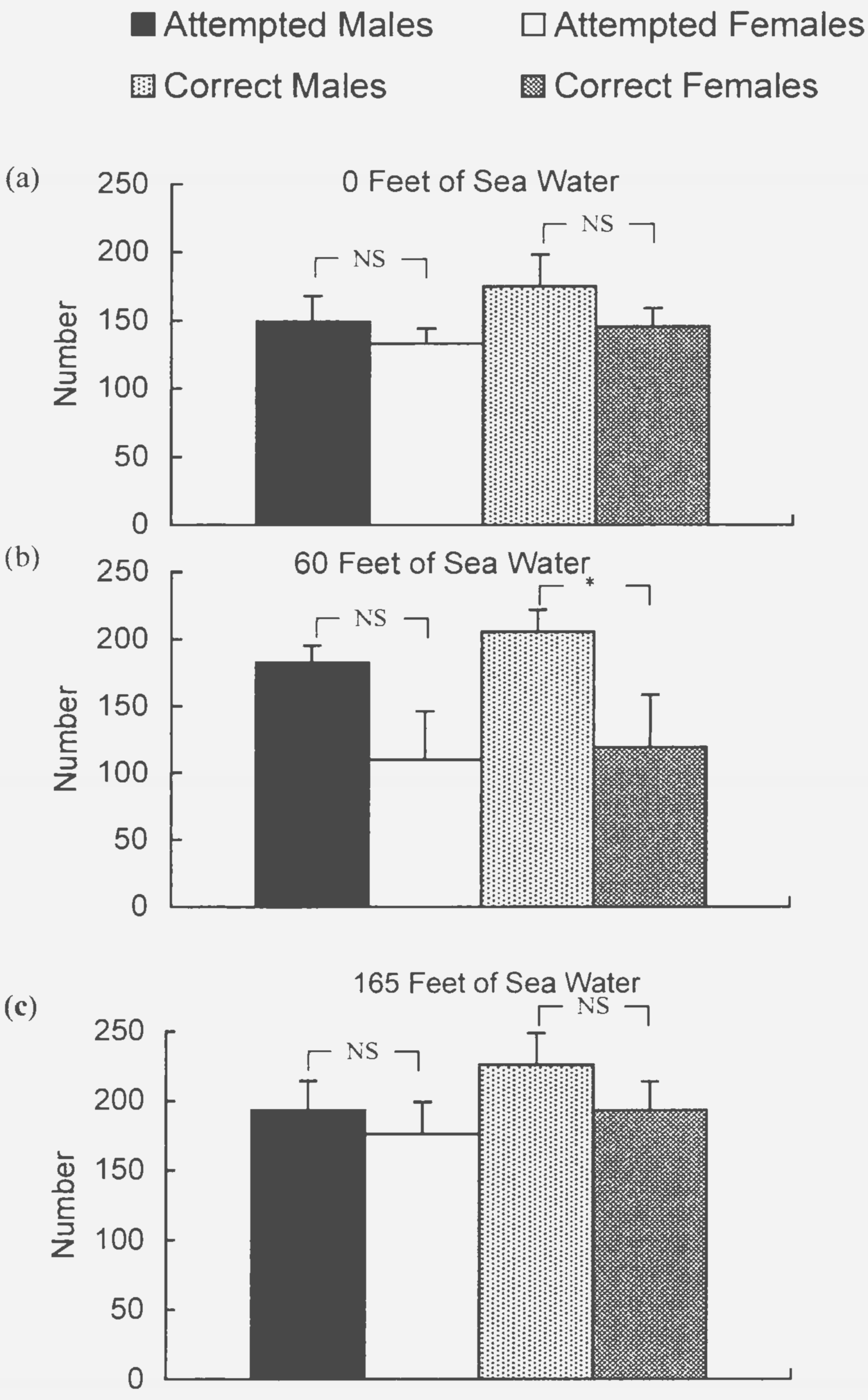
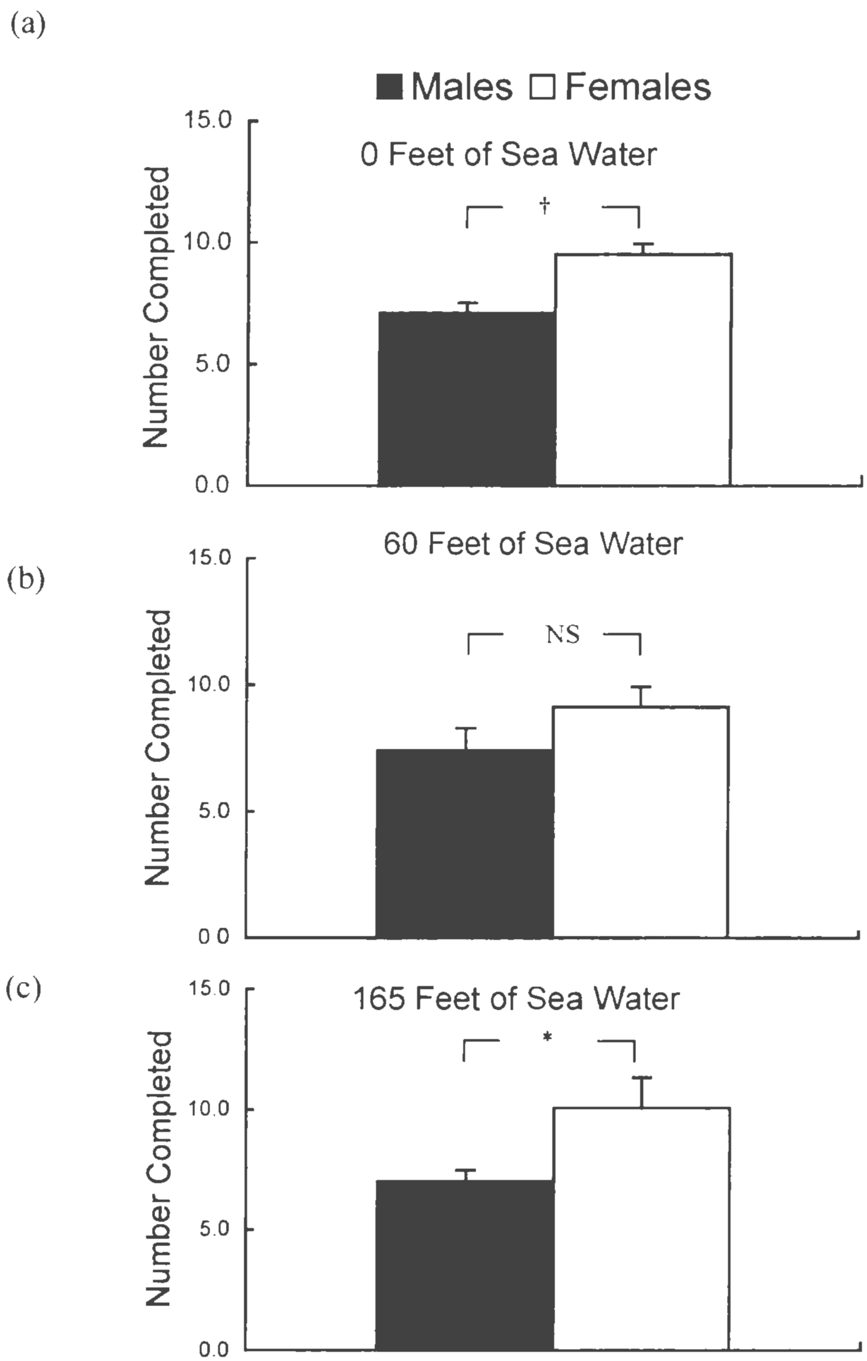


Figure 3-6. Modified Purdue Pegboard Test scores for males and females at depths of (a) 0, (b) 60 and (c) 165 feet of sea-water in a hyperbaric chamber. Bars indicate the mean response observed and error bars indicate standard error of the mean (NS= Non Significant, * $p<0.05$, $^{\dagger}p<0.01$, $^{\ddagger}p<0.001$).



Chapter 4: Comparison of Recognition Memory plus Cognitive and Psychomotor Performance in Males and Females while Breathing 30% Normoxic Nitrous Oxide

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Keywords: gender, cognition, inert gas narcosis, psychomotor, diving, hyperbaric

4.1 Abstract

The effects of inert gas narcosis on cognitive and psychomotor performance were examined with respect to gender. Six female and six male participants were tested at 1 Atmosphere Absolute (ATA) breathing air or breathing a 30% normoxic nitrous oxide mixture. Cognition was evaluated using a simple arithmetic test, a modified Stroop test, a number comparison test and a long-term recognition memory test. Psychomotor ability was evaluated using a matrices drawing test and a modified Purdue peg-board test. Irrespective of Gender, an effect of Gas Condition was seen in all cognitive tests except the matrices drawing test; significantly lower scores ($0.006 < p < 0.03$) were evident for the nitrous oxide relative to the air condition. Excluding the recognition memory test, there was no main effect of Gender across the test battery. For the recognition memory test females showed a significant lower level of memory ($p=0.006$) while breathing 30% normoxic nitrous oxide relative to males breathing the same gas mixture. This difference appeared to be due to a pre-existing difference as it was also evident during air breathing. In conclusion, the results of this experiment support the hypothesis of no gender differences in cognitive and psychomotor ability during inhalation of 30% normoxic nitrous oxide.

Keywords: cognition, diving, gender, hyperbaric, inert gas narcosis, memory, psychomotor

4.2 Introduction

Nitrogen narcosis is the effect produced by the gas nitrogen when it is breathed under increased pressure. Diving below 100 feet of sea-water (fsw) produces major cognitive and physiological effects known as "rapture of the depths" or nitrogen narcosis (1, 16). Symptoms of nitrogen narcosis include emotional and psychological declines (16), impaired auditory perception (12), and slowed in reaction time (11). Nitrogen has high lipid solubility and is easily absorbed into the central nervous system (1). Meyer and Overton (18) first noted a relationship between the solubility of an inert gas and its narcotic potency and they concluded that all gaseous substances induce narcosis if they penetrate cell lipids in a definite molar concentration. This suggests that the higher the oil-water partition coefficient, the more potent the inert gas. By extension, it can be concluded that when a high concentration of nitrogen is breathed, the nervous system becomes saturated with the inert gas, and normal functions are impaired. Meyer and Overton hypothesized that an increased oil-water partition coefficient is proportional to an increased narcotic potency of a gas. Higher levels of adiposity are therefore often associated with a greater "loading" of nitrogen (13, 14). This view may be unwarranted since the nitrogen narcosis acts on central nervous system tissues, however, some studies in support of this view (5, 6, 22) show females may have a greater disposition to DCS, presumably due to greater loading of nitrogen onto their tissues.

The majority of the studies investigating nitrogen narcosis are conducted using a hyperbaric chamber to simulate a given diving depth. It has been shown that breathing 30% nitrous oxide (N_2O) produces similar narcotic effects as breathing compressed air at 6ATA (2). Nitrous oxide, therefore, has been used to simulate compressed air narcosis (2).

A study conducted by Biersner (2), examined the emotional and physiological effects of nitrous oxide and hyperbaric air narcosis. The Biersner (2) study concluded that nitrous oxide does not appear to benefit emotional or physiological adaptation to nitrogen narcosis associated with breathing hyperbaric air. It may, in fact, impair emotional adaptation under these experimental conditions.

Although the cognitive effects of nitrogen narcosis are well established in men, there has been very little research studying these effects on women. In addition, an exhaustive literature review has not uncovered tests of cognition using nitrous oxide across gender. In this research study, we used 30% nitrous oxide, 21% O_2 and balance N_2 and measured cognitive and psychomotor performance changes in males and females relative to the same tests given when subjects breathed air.

4.3 Materials and Methods

4.3.1 Participants

Six healthy males and six healthy females volunteered from the university population. All participants were given complete confidentiality as well as information and instructions regarding the experimentation and the possible adverse effects. Ethical and medical approval was obtained for each participant who also signed an informed consent prior to participation. The set of experiments were given ethical clearance by the Memorial University Human Investigations Committee and the Dalhousie University Human Research Ethics Board. The research conformed with the Helsinki declaration. The number of participants was determined using a power calculation based on previous results (8), with an α level of 0.5 and a β value of 0.8. The participants' characteristics appear in Table 4-1. From study 1 in Chapter 3, four of six females and five of six males participated in this study reported in Chapter 4.

4.3.2 Instrumentation

The experiment was conducted in the Laboratory of Exercise and Environmental Physiology at the Memorial University School of Human Kinetics and Recreation. The experiment was conducted employing a 350 liter Tissot Spirometer (Model 1464, Boston Massachusetts, USA), a mouthpiece, and a nose clip to supply the inspired gas to the participant. The gases employed were room air (control) and a narcotic gas mixture containing 30% nitrous oxide, 21% oxygen and balance nitrogen.

Other equipment need for the research included. approximately five #2 pencils. a stopwatch, and 6 different cognitive and psychomotor tests. The 6 cognitive tests used were: a modified Stroop test, an arithmetic test, a number comparison test, a matrices drawing test, a modified Purdue pegboard test, and a recognition memory test.

4.3.3 Body Composition Tests

Each participant participated in three separate tests to analyze their body composition. The tests used were skinfold test, a bioelectric impedance test -impedance with a monitor (Tanita Model TBF521, Tokyo, Japan) and DEXA analysis. These values appear in Table 4-1.

Skinfolds

The skinfold test was completed using a Harpenden skinfold caliper. The participant's height, weight and date of birth were recorded before the test. The participant was asked to relax during the test to aid in manipulation of the skinfold. Skinfolds were raised by the measurer's fingers at the selected sight. The measurer grasped the folds with the index finger and thumb of the left hand. The caliper pressure plates were applied 1 cm below the edge of the grasping fingers. The caliper was always applied at a right angle to the fold and distal to the pinching fingers. Measurements were read after 2 s of applied pressure. Skinfolds were measured at 8 different sites: triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, medial calf. Each skinfold was completed once before repeating the procedure a second or third time. For each skinfold site, the two trials yielded results within 5% or the median value was recorded. A sum of the 8 skinfold sites was recorded.

Bioelectric Impedance

The subject's adiposities were estimated with a bioelectric impedance monitor (Tanita Model TBF521, Tokyo, Japan).

DEXA Analysis

The DEXA analysis was conducted on each participant in the Nuclear Medicine department of the Memorial University Health Science Centre. The test required approximately 20 minutes of the participant's time. The test involved the participant lying still in a supine position and it was essential that the individual being tested wear no metal during the testing. The DEXA machine slowly scanned the entire body recording accurately the individual's body composition. A computer record of the results was obtained.

4.3.4 Cognitive and Psychomotor Tests

Modified Stroop Test

This test consisted of the words red, blue, yellow green and black printed on a page, followed by 10 letters. The color name was printed either in its own color or in a different color then the word. If the color was printed in its own color the participant would cross out the succeeding vowels, otherwise consonants from the same adjacent list of 10 letters were crossed out. Overall performance on the test was calculated according to the number attempted, the number correct, and the number of errors within a time period of one minute. This test is considered a measure of stress sensitivity in decision making (21)

Arithmetic Test

The arithmetic test was made up of 48 different arithmetic problems, each consisting of adding or subtracting the result of one-digit by one-digit multiplication from a two-digit number, such as 37 + 6 x 8 or 31 - 8 x 5. The participants were instructed to multiply first, and then to add or subtract, and were asked to solve as many problems as possible in two minutes. This test gave a combined measure of speed and accuracy. They were also instructed that a question skipped or missed would be regarded as incorrect. Participants were instructed to complete the problems in the order presented. In addition, participants were instructed to begin at the upper left hand corner of the test at #1 and proceed down the left column and then to the top of the right hand column at #25. The scores recorded consisted of the number of problems attempted as well as the number of correctly and incorrectly solved problems. A missed problem counted as an error, and lowered the score of a participant who answered only the easy questions. A partially answered problem was not counted as an attempted problem. All of the arithmetic tests were timed with a stopwatch. A single score sensitive to both speed and accuracy was then computed using the formula:

$$\text{SCORE} = \frac{(\text{Number correct x 2})}{(\text{Number attempted} + 48)} \quad \text{X 100}$$

To score 100% the participant needed to complete all 48 problems correctly within two minutes. To obtain a good score the participant is required to work fast and accurately.

e.g. 24/26 gives a score of 48/74 x 100 = 65%

Number Comparison Test

This test required participants to examine pairs of 6 digit numbers and indicate whether the numbers in each pair were the same or different. The performance was scored on the number marked correctly, the number marked incorrectly, and the total number attempted in a time period of 45 s. This test measures perceptual speed (7). A single score sensitive to both speed and accuracy was then computed using the formula:

$$\text{SCORE} = \frac{(\text{Number correct x 2})}{(\text{Number attempted} + 48)} \text{ X 100}$$

To score 100% the participant must complete all number comparisons correctly within the 45 s period. To obtain a good score the participant was required to work fast and accurately.

e.g. 24/26 gives a score of 48/74 x 100 = 65%

Matrices Drawing Test

Each item consisted of a four-line geometric configuration and a square matrix of dots. The task was to replicate as close as possible the figure onto the dots. This task requires flexibility of closure in the act of superimposing the particular shape on a strong visual field (7). Participants were asked to work as accurately and as fast as possible. The score was the number of correctly copied patterns, or portions of patterns, in a time period of 2 min. In addition, the number or portion of patterns attempted, as well as errors, were recorded (8).

Modified Purdue Pegboard Test

For this task, participant used both hands at the same time. They were asked to assemble a series of pins, collars, and washers in the order of (for one assembly) a pin, a washer, a collar, and a washer. The score recorded was the number of individual parts assembled in 1 min. This task measures fine manual dexterity (20).

Recognition Memory Test

A recognition memory test was administered. Participants viewed a 16-word list for 3 minutes and were instructed to remember as many words as possible. A 5-min delay was interposed between learning and recognition in both conditions. To help control effects of disruption, participants were asked to perform simple arithmetic calculations during the 5-min delay. The participants were then given an additional 5-min to circle as many of the original list as possible from a list of 100 words (that included the original 16, randomly placed). Only 16 choices were allowed in the recognition portion of the test. A mean recognition score (the number of correct responses) was recorded.

4.3.5 Protocol

Each participant was first given a practice session including a minimum of 5 trials of each of the cognitive or psychomotor tests or until there was a plateau in performance. The control value for the subsequent analyses was the average of a minimum of 3 trials once a plateau in performance had been achieved. The participants participated in two experimental sessions lasting approximately 20 minutes: one session breathing air, and one session breathing the 30% nitrous oxide, 21% O_2 and 49% N_2.

To begin, the participants were asked to wear a head apparatus, which holds the mouthpiece securely and comfortably in place. The mouthpiece was attached with Collins tubing to the Tissot spirometer for breathing the nitrous oxide.

The participant was asked to relax, face forward and place the mouthpiece in his/her mouth. When the investigator indicated that the valve was open, the participant placed his/her nose clip on and began breathing through the facemask. For the first 20-min session, the participant breathed either air or nitrous oxide through the facemask. When the 20-min period ends, the participant was asked to remove the facemask and nose clip. On day two, following the same procedure as day one, the participant breathed the second gas mixture. The order that the gases were presented was randomized and counterbalanced between participants. Each participant was unaware of which order the gasses were being administered. The atmosphere in the lab was quiet with limited distractions.

The level of gas in the Tissot spirometer was recorded at the beginning and end of each 20-min session.

4.3.6 Statistical Analysis

The test results obtained in the pre-test conditions and while breathing air were each compared with the test results obtained while breathing nitrous oxide using a split-plot two-way ANOVA. Factors in the model were of Gas Condition (Levels: Pre-Test, Air, N_20) and Gender (Levels: Male, Female). In the ANOVA models degrees of freedom for Gas Condition were 2 and for Gender were 1. The results were considered significant at a level of 0.05. Post hoc tests employed were orthogonal contrasts within a gender across levels of Gas Condition and one-way ANOVAs between the males and females at each level of Gas Condition. The statistical software package employed was SuperANOVA (version 1.11, Abacus Concepts, CA, USA).

4.4 Results

The comparison across gender for age and anthropometry (Table 4-1) indicated males were of the same age ($p=0.18$) but were significantly heavier ($p<0.01$) and taller ($p<0.01$) than the females. Body composition analyses indicated that for both bioelectric impedance ($p<0.05$) and the DEXA method ($P<0.05$) the females had significantly greater levels of adiposity. The skinfold measurement showed no difference across gender.

The modified Stroop test results are given in Figure 4-1. Results indicated no main effect of Gender for the number attempted ($F=2.1$. $p=0.21$). However for the number attempted in the Stroop test there was a trend for a main effect of Gas Condition ($F=3.8$. $p=0.06$). This trend was explained by significantly lower mean number attempted of 37.9 ± 3.5 (mean is pooled across Gender) in the nitrous oxide condition relative to 42.7 ± 1.7 attempted in the pre-tests and 44.3 ± 2.4 attempted in the air condition. For the number correct in the Stroop test there was no main effect of Gender ($F=0.88$, $p=0.39$) but correct scores were significantly lower in the nitrous oxide condition ($p=0.03$) relative to air or pre-test condition and this explained the significant main effect of Gas Condition ($F=5.4$. $p=0.03$). No interactions between Gas Condition and Gender were evident in the modified Stroop test results.

Arithmetic test results are given in Figure 4-2. For the arithmetic test, there was no main effect of Gender for the number correct ($F=0.04$, $p=0.86$), and the number attempted ($F=0.03$. $p=0.91$). For the number attempted in the arithmetic test. there was no main effect of Gas Condition ($F=0.99$, $p=0.40$). However, for the number correct in the arithmetic test, there was a main effect of Gas Condition ($F=13.5$, $p=0.001$) that was explained by significantly lower scores of 9.5 ± 1.9 in the nitrous oxide relative to that of 13.5 ± 1.1 in the air condition ($p=0.001$) and 13.4 ± 1.4 in the pre-test condition ($p=0.001$). No interactions between Gas Condition and Gender were evident for the arithmetic test.

In Figure 4-3 the number comparison results are given and they showed no main effect of Gender for either the number attempted ($F=0.33$, $p=0.59$) or number correct ($F=0.47$, $p=0.52$). There was a main effect of Gas Condition for number of matches attempted ($F=6.3$, $p=0.02$) and for the number of correct matches ($F=8.8$, $p=0.006$). The Gas Condition main effects for number attempted and number of correct matches were explained by scores pooled across Gender. The number of matches attempted of 20.2 ± 1.6 in the nitrous oxide condition were significantly lower than the values of 24.9 ± 1.7 ($p=0.04$) in the pre-test condition and of 27.4 ± 2.5 in the air breathing condition ($p=0.006$). The number of correct matches was 19.2 ± 1.7 in the nitrous oxide condition and it was significantly lower than that of 24.6 ± 1.6 correct matches in the pre-test condition ($p=0.02$) and that of 27.2 ± 2.5 correct matches in the air condition ($p=0.002$). No interactions between Gas Condition and Gender were evident for the number matching tests.

Matrices drawing scores are given in Figure 4-4. There were no main effects of Gender for number attempted (F=0.24, p=0.65) or number correct (F=0.17, p=0.70). There was also no main effect of Gas Condition for number attempted (F=1.9, p=0.20) or number correct (F=0.27, p=0.81). No interactions between Gas Condition and Gender were evident for the matrix drawing test.

Manual dexterity was tested with the modified Purdue Pegboard test (Figure 4-5). There was no main effect of Gender (F=1.79, p=0.24) but there was a main effect of Gas Condition (F=8.0, p=0.009). There was also a significant Gender by Gas Condition interaction term (F=5.7, p =0.02) for the pegboard test that was explained by significantly greater scores for females in the pre-test (p=0.006) and air (p=0.01) conditions that decreased to a level that was not significantly different across Gender in the nitrous oxide condition.

Long-term memory results, tested using a recognition memory test, are given in Figure 4-6. A significant main effect of Gender was evident (F=47.0, p=0.001). Female and male scores for memory were the same in the pre-test condition. However, females relative to males had lower memory scores in the air (p=0.03) and in the nitrous oxide (p=0.006) conditions. There was no significant main effect of Gas Condition and there was no Gender by Gas Condition interaction for the memory test.

4.5 Discussion

With the exception of recognition memory, from the cognition and psychomotor tests employed there were no significant main effects of Gender under these conditions. This supports females performed as well as males in these conditions and supports the hypothesis of no gender-based difference for cognitive psychomotor abilities during nitrogen narcosis. This result was despite the females having a significantly higher level of adiposity (Table 4-1). The exception to this result was for the long-term memory test. In the recognition memory test females showed significant decrements in long term memory while males in the study showed no significant changes in long term memory (Fig. 4-6). Females had lower memory scores in air ($p=0.03$) and nitrous oxide ($p=0.006$) relative to males. This might suggest the lower memory scores were preexisting in our sample. As such it appeared overall that females have similar cognitive and psychomotor performance as males during nitrogen narcosis induced by nitrous oxide with the exception of the long-term memory test.

With the exception of the matrix drawing test the results of this study indicate that, overall, irrespective of Gender, that cognitive and psychomotor ability were significantly impaired when participants breathed the 30% nitrous oxide gas mixture. The pooled means across Gender for each test, in each condition showed significant decrements in performance for participants breathing the normoxic nitrous oxide mixture relative to the pre-test or air conditions. This Gas Condition effect was evident for attempted and correct scores for both the modified Stroop test (Fig 4-1) and number comparison test (Fig 4-3). Also nitrous oxide breathing gave significantly fewer correct arithmetic scores (Fig 4-2). The matrices drawing test results, again irrespective of Gender, showed no main effect of Gas Condition for the number of correct or attempted responses. This suggested that the matrices drawing test may not have been an effective instrument for discerning psychomotor impairments that exist in nitrogen narcosis.

In comparison to the study by Fothergill el. al. (8), that we employed to help create our test battery, our test results were similar. As in Fothergill et al. (8), our study showed significant decrements in cognitive performance with the exception of the matrices drawing tests. Fothergill and colleagues stated that under their experimental conditions nitrogen narcosis produced significant impairment through both decreases in the speed and accuracy. Here speed is quantified with the scores for the number of attempted tests or matches and accuracy is quantified with the number of correct responses. As such, irrespective of Gender, 30% normoxic nitrous oxide was successful in impairing speed and accuracy of the cognitive and psychomotor tests that we employed, as is widely reported in the literature (10).

In comparison to an earlier study by Biersner et. al. in 1972 (3), which showed that fine and gross motor performance was not disrupted while breathing nitrous oxide, our results differed. The results of our study indicate that gross motor performance and finger tip dexterity, measured using a modified Purdue pegboard, were disrupted to a similar extent in both males and females breathing 30% normoxic nitrous oxide (Fig. 4-

5). Our findings were more similar to those (4) which indicated that complex psychomotor ability was impaired significantly during nitrogen narcosis at a simulated depth of 170 feet. There does not appear to be a gender difference for manual dexterity tests such as the Purdue pegboard test (15).

With respect to our long-term memory test, our study showed similar results to those found by Biersner et. al. (3) which also examined long-term memory (LTM) while participants breathed a 30% nitrous oxide solution. They showed that long-term memory, in male participants, examined by a forward and backward digit span task, remained normal under these conditions. Our results also showed that for our male participants, there were no significant decreases in recognition memory under these conditions. Also, in comparison to a study conducted by Fowler and colleagues (9) which tested long LTM with participants breathing a 35% nitrous oxide solution, our results differed. In contrast to our findings, Fowler et. al. (9) found significant impairments in LTM when male participants breathed the nitrous oxide solution. However, our results did show an effect of Gas Condition among our female participants for the recognition memory test and this would support Fowler's study (9).

As demonstrated in this study and previous studies, cognitive impairment does exist at depths greater than 60 feet below sea level. The proposed mechanisms for this phenomenon are numerous. Inert gas narcosis may be produced by the same mechanisms as general anesthesia with the narcotic properties of gases or volatile liquids acting on the central nervous system (6). Several different hypotheses have been formed to clarify the possible mechanisms behind narcosis. The Meyer and Overton hypothesis (18) stated that there is a parallel between the solubility of an anesthetic in lipid and its narcotic potency. The molecular weight theory suggests that the narcotic effect of inert gases increases with their molecular weight, therefore nitrogen with a molecular weight of 28 would be quite potent (1, 6). The hydrate formation hypothesis suggests that narcosis is related to the stability of the gas hydrates formed in aqueous solution. Contrary to the lipid theory, this theory suggests that the anesthetic molecule is associated with water molecules rather than lipid molecules (19). In addition to these theories, there are also some physical theories based on the polarizability and volume of the inert gas molecule as well as some biochemical hypothesis that have been used to explain the mechanisms of narcosis.

As evident by some of these hypotheses mentioned above, it has been suggested that females, with a higher average percent body fat are more susceptible to the effects of nitrogen narcosis. According to a study conducted by Hart et. al. in 1981 (14) and the Meyer-Overton Hypothesis of inert gas narcosis (17, 18) it was expected that the female participants, with a higher body fat composition than their male counterparts, would show more performance decrements on all tasks. Our results, however, indicated that recognition memory was the only task that showed significant performance decrements by the female participants in comparison to the male participants despite that females had significantly higher levels of adiposity (Table 4-1). It must be mentioned this difference in recognition memory might have been to a pre-existing difference in the sample. Research thus far has provided no studies with which to compare our gender results.

4.6 Conclusion

Overall, this study has indicated that there are few differences between genders with respect to cognitive and psychomotor ability under inert gas narcosis. There was no significant difference in cognitive ability between males and females as indicated by the arithmetic test, the modified Stroop test, the number comparison test or the matrices drawing test at 1ATA when breathing 30% nitrous oxide, 21% oxygen and nitrogen balance. There was a significant difference in cognitive ability between males and females as indicated by the recognition memory test at 1ATA when breathing 30% nitrous oxide, 21% oxygen and nitrogen balance. This may have been explained by a pre-existing difference in memory across gender as was evident for the air condition.

With respect to the practical implications of this study, women can be considered equal to their male counterparts when it comes to cognitive ability for the conditions of an inert gas induced narcosis. Very little research was available with which to compare these results. In this study the element of memory was added to further investigate cognitive ability between men and women at depth. There are still other aspects of cognition such as coordination and short-term memory that could be investigated in future research. More research in the area of cognition and gender, especially memory, needs to be completed in order to provide confirmation of these results.

4.7 Acknowledgements

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4.8 References

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Table 4-1. Participant profiles for females (a) and for males (b) who were assessed for cognitive and psychomotor skills while breathing a gas mixture of 30% nitrous oxide, 21% oxygen, balance nitrogen. Values in the table are mean ± the standard error of the mean (SE). (Bioelectric Impedance (BI); Dual Energy X-ray Absorptiometry (DEXA) (NS= Non Significant, * $p<0.05$, $^{\dagger}p<0.01$, $^{\ddagger}p<0.001$).

(a)

Gender	Age (y)	Height (cm)	Weight (kg)	BI Adult (% Fat)	BI Athlete (% Fat)	∑ Skinfolds (mm)	DEXA (% Fat)
F	24	146.5	44.9	25.5	25.0	126.8	29.0
F	22	156.0	50.9	29.5	24.5	141.8	32.8
F	25	161.5	67.9	32.0	23.5	119.8	26.9
F	26	164.0	58.3	29.0	20.5	119.0	29.7
F	22	168.4	70.4	23.5	33.0	125.5	25.5
F	35	166.5	50.4	25.0	17.0	62.8	18.2
Mean	26	160.5	57.1	27.4	23.9	115.9	27.0
SE	2	3.3	4.2	1.3	2.2	11.1	2.0

(b)

Gender	Age (y)	Height (cm)	Weight (kg)	BI Adult (% Fat)	BI Athlete (% Fat)	∑ Skinfolds (mm)	DEXA (% Fat)
M	43	172.0	73.6	20.5	13.5	123.4	23.1
M	45	179.5	101.5	28.0	17.0	103.9	20.1
M	25	178.5	86.7	24.5	16.0	85.2	19.7
M	38	187.0	91.3	25.0	17.5	156.0	23.6
M	22	173.0	67.0	18.0	15.0	88.6	22.3
M	22	184.0	75.2	14.5	7.5	70.4	14.5
Mean	33^{NS}	179.0^{*}	$82.6^{\dagger}$	21.8^{*}	$14.4^{\dagger}$	104.6^{NS}	20.6^{*}
SE	4	2.4	5.3	2.0	1.5	12.6	1.4

Figure 4-1. Modified Stroop test scores for number attempted and number correct for males and females in pre-test (a), breathing air (b), and breathing 30% normoxic nitrous oxide (c) conditions. Bars indicate the mean response observed and error bars indicated standard error of the mean (NS= Non Significant, * $p<0.05$, † $p<0.01$, ‡$p<0.001$).

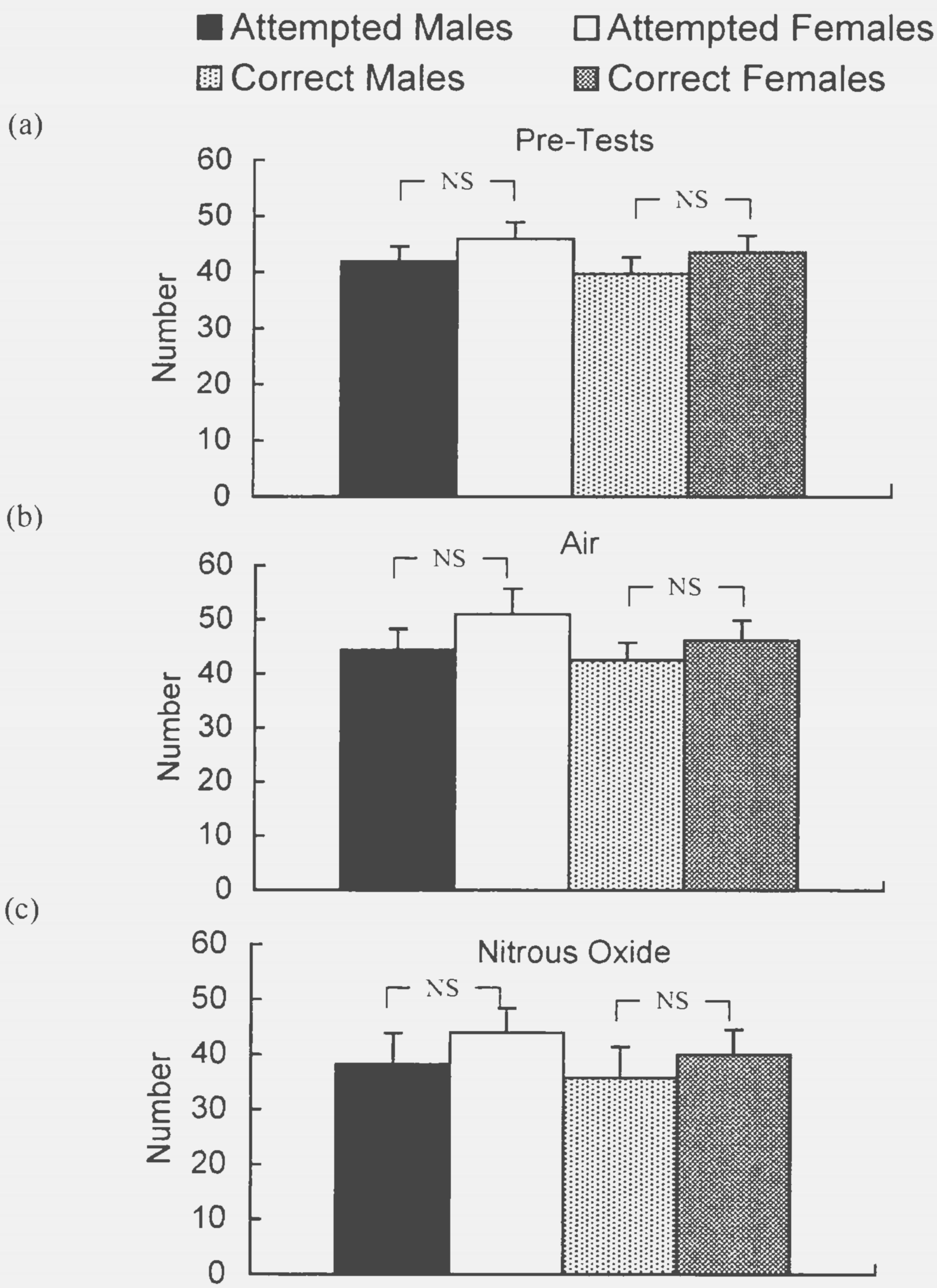


Figure 4-2. Arithmetic Test Scores – number attempted and number correct for males and females in the pre-test (a), breathing air (b), and breathing 30% normoxic nitrous oxide (c) conditions. Bars indicate the mean response observed and error bars indicated standard error of the mean (NS= Non Significant, * $p<0.05$, †$p<0.01$, ‡$p<0.001$).

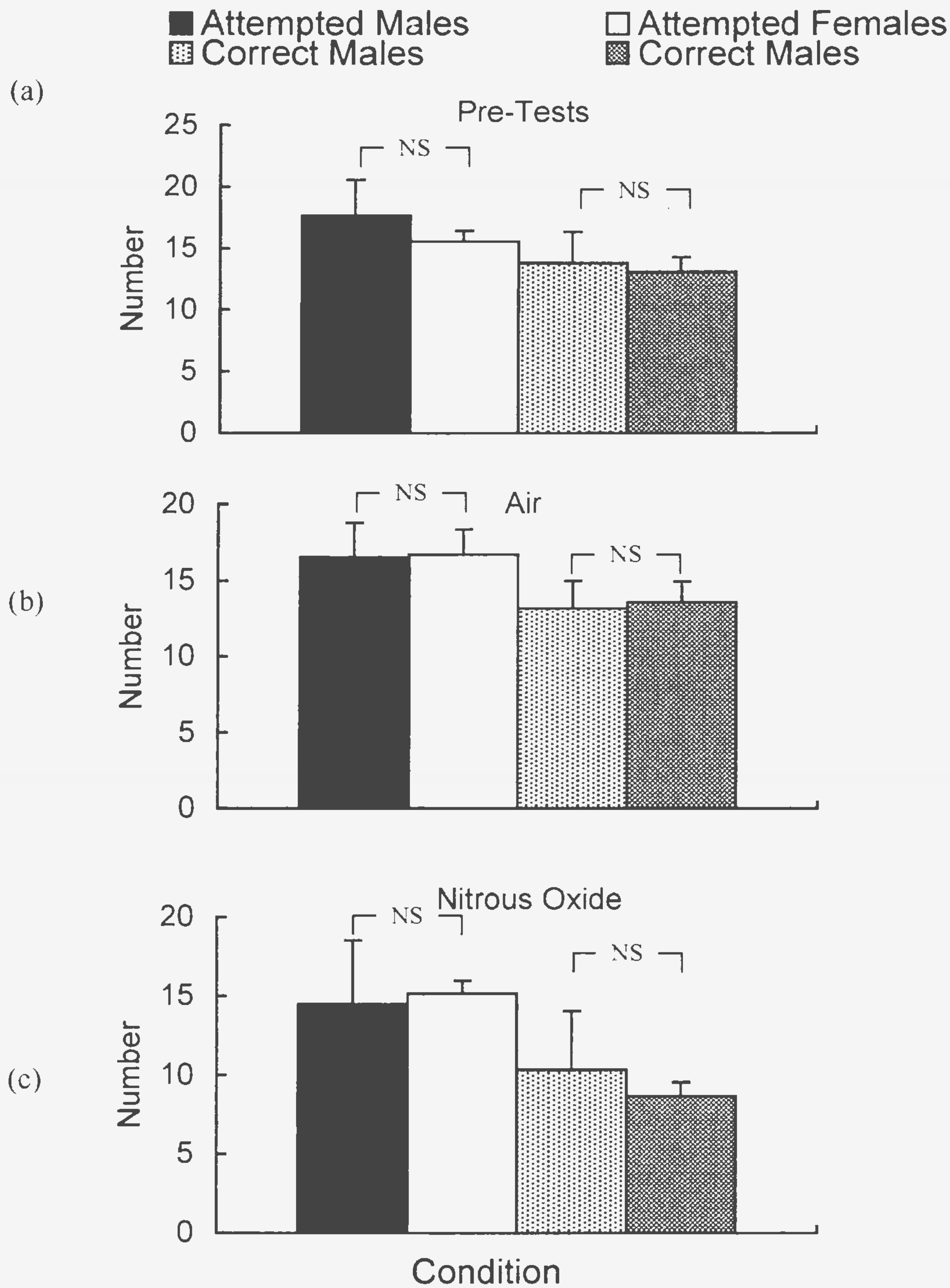


Figure 4-3. Number Comparison Scores number attempted and number correct for males and females in the pre-test (a) , breathing air (b), and breathing 30% normoxic nitrous oxide (c) conditions. Bars indicate the mean response observed and error bars indicated standard error of the mean (NS= Non Significant, * $p<0.05$, $^{+}p<0.01$, $^{\ddagger}p<0.001$).

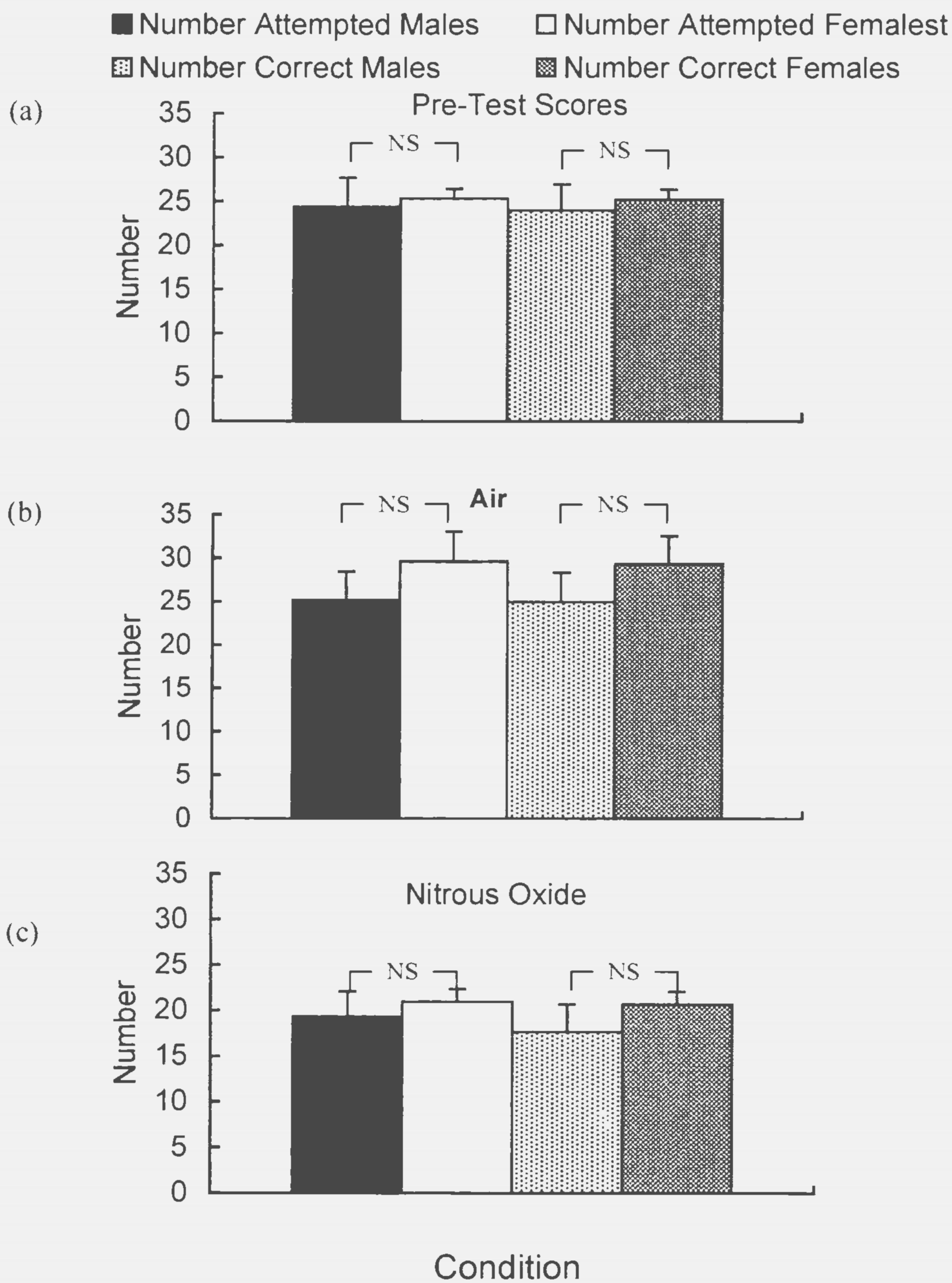


Figure 4-4. Matrices Drawing Test Scores number attempted and number Correct and for males and females in the pre-test (a), breathing air (b), and breathing 30% normoxic nitrous oxide (c) conditions. Bars indicate the mean response observed and error bars indicated standard error of the mean (NS= Non Significant, * $p<0.05$. † $p<0.01$, ‡ $p<0.001$).

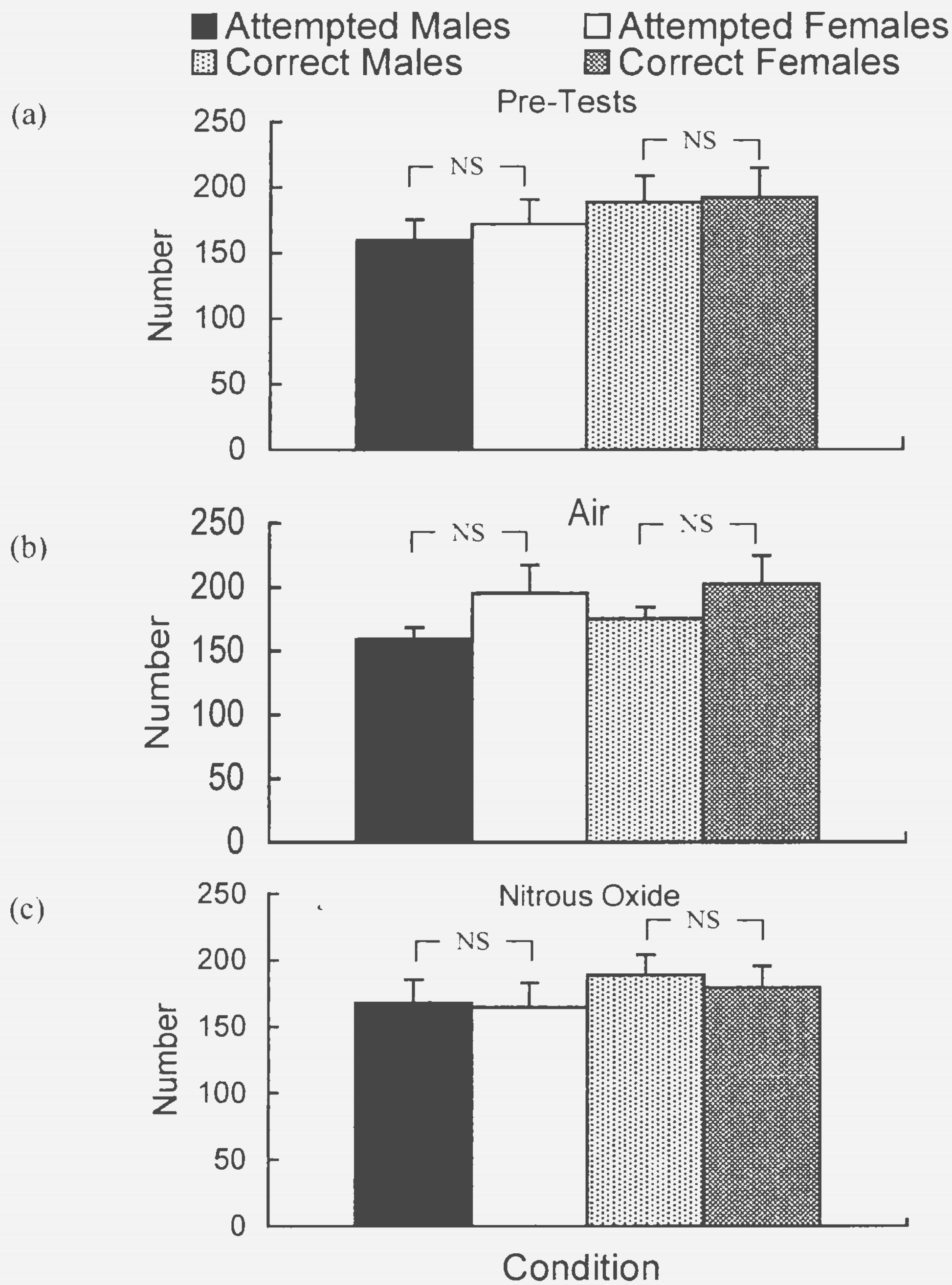


Figure 4-5. Modified Purdue Pegboard Test scores for males and females in the pre-test (a), breathing air (b), and breathing 30% normoxic nitrous oxide (c) conditions. Bars indicate the mean response observed and error bars indicate the standard error of the mean (NS= Non Significant, * $p<0.05$, † $p<0.01$, ‡ $p<0.001$).

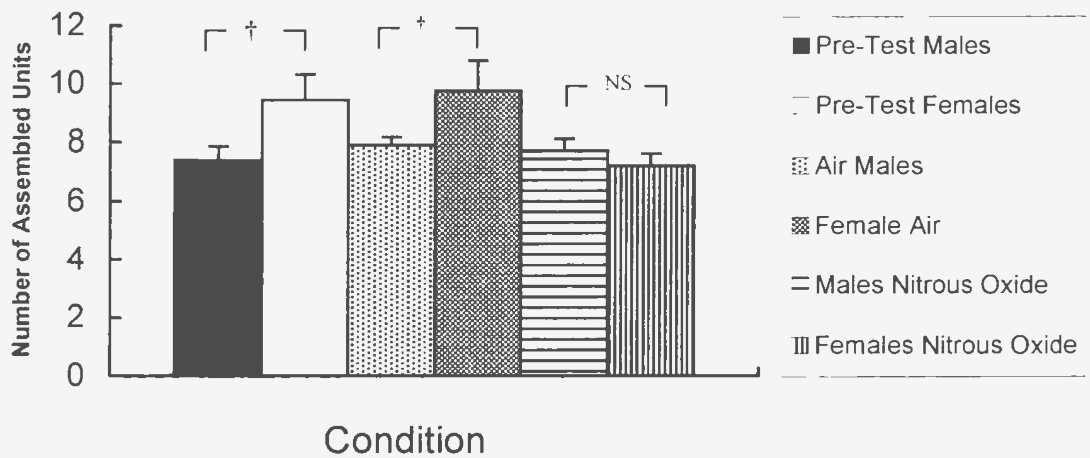
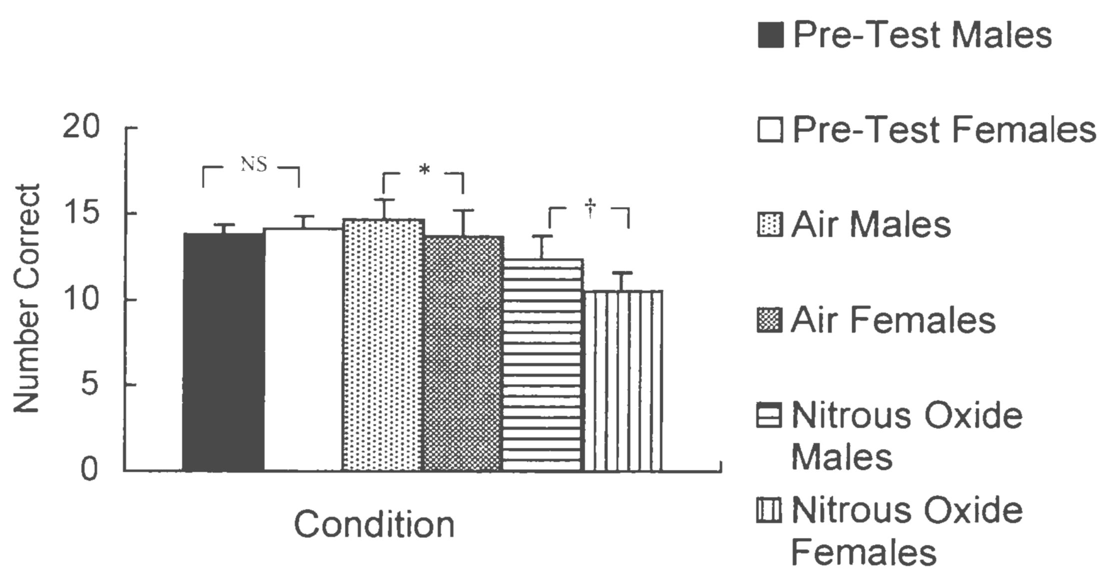


Figure 4-6. Recognition Memory test scores for males and females in the pre-test (a), breathing air (b), and breathing 30% normoxic nitrous oxide (c) conditions. Bars indicate the mean response observed and error bars indicate the standard error of the mean. (NS= Non Significant, * $p<0.05$, $^{\dagger}p<0.01$, $^{\ddagger}p<0.001$).



Chapter 5: Thesis Summary and Conclusions

5.1 Research Hypotheses Replies

This thesis tested the null hypotheses that: a) that nitrogen narcosis at different depths (60 fsw and 165 fsw) will have no significant effect on cognitive and psychomotor ability across Gender, and b) nitrogen narcosis at 1ATA induced with 30% nitrous oxide, 21% oxygen and balance nitrogen will have no significant effect on cognitive and psychomotor ability across Gender.

Both studies showed evidence that cognition and psychomotor ability are affected under simulated diving conditions, although effects of depth in the hyperbaric chamber in Study 1 (Chapter 3) were only evident for scores from the arithmetic and matrices drawing tests. At both depths in study 1 the females overall scores, as judged from the main effects in the repeated measures ANOVA models, were not significantly different from the males. As judged from the across Gender contrasts at 60 fsw, in some cognitive and psychomotor tests, the females outperformed males. These differences across Gender were generally no longer evident at a depth of 165 fsw. As such the null hypothesis of no effect of Gender at depth was accepted.

In study 2 (Chapter 4) there were no significant main effects of Gender for all tests employed with the exception of the long-term memory test where females scored significantly lower than males when breathing air or nitrous oxide. It appears the difference across Gender may have been in part due to the preexisting difference in memory across Gender as was evident in the air condition. With this exception in mind, the null hypothesis of no differences across Gender for cognitive and psychomotor performance during nitrous oxide breathing was accepted.

5.2 Testable Questions Replies

Using an arithmetic test, number comparison test, modified Stroop test, matrices drawing test, modified Purdue Peg Board test, and recognition memory test the questions that were addressed in this thesis and their replies are :

1. Is there a significant difference in cognitive ability between men and women when diving to a depth of 60 fsw?

There were some significantly better performances for females than males for the each of the cognitive and psychomotor tests at 60 fsw.

2. Is there a significant difference in cognitive ability between men and women when diving to a depth of 165 fsw?

There were significantly better performances for females than males for the modified Stoop test and for the Modified Purdue pegboard test at 165 fsw. For all other cognitive and psychomotor tests at 165 fsw there were no significant differences across Gender.

3. Is there a significant difference in cognitive or psychomotor ability between men and women at 1ATA when breathing 30% nitrous oxide. 21% oxygen and nitrogen balance?

There were no significant differences between females and males for the modified Stroop, the arithmetic test, the number comparisons or the matrices drawing test. For the pre-test and while breathing air, females performed significantly better than males on the modified Purdue Pegboard.

4. Is there a significant difference in long-term memory ability between men and women at 1ATA when breathing 30% nitrous oxide, 21% oxygen and nitrogen balance?

Females scored significantly lower than males on the long-term memory test when breathing 30% nitrous oxide, 21% oxygen and balance nitrogen.

More research comparing male and female divers needs to be completed to gain a fuller understanding of differences in cognition and psychomotor performance that may exist during nitrogen narcosis More specifically, future studies should focus on the memory capacity of both male and female divers.

Chapter 6: Overall Thesis References

6.1 Overall References (Alphabetical)

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Appendix 1-Sample Sections of Cognitive Tests Employed

1. Sample Modified Stroop Tests

GREEN	H I U B U X L I K U
BLACK	N O H U I X U P U M
YELLOW	A A R V U H G M Q B
BLUE	R Q J U D K D A I H
BLACK	A C U P H A F A U U
YELLOW	E U I P U X N L U R
BLUE	**O U J T W B N Q I E**
GREEN	**O V R N I I O P M S**
YELLOW	S I P Q A U Z U M O
BLUE	**A U A B J U B D H K**
GREEN	**R O A O A N M V O D**

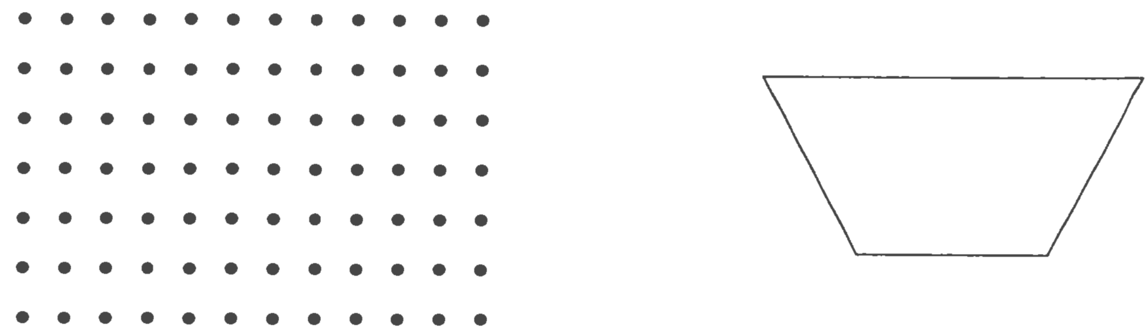
2. Sample Arithmetic Test

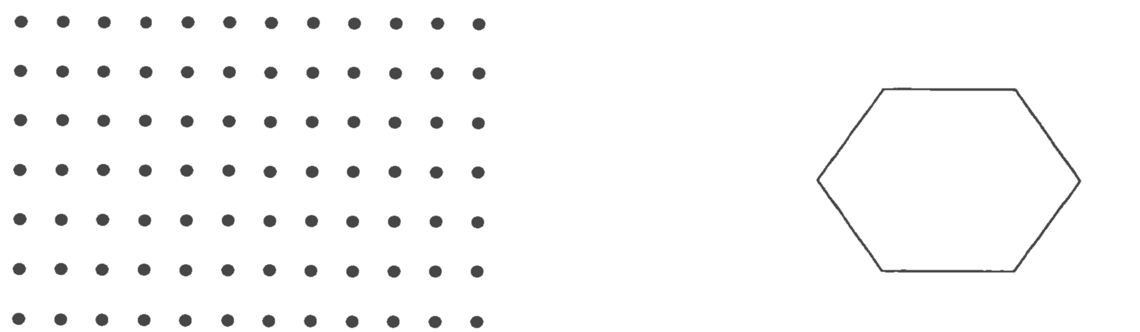
Name: ____________________ Date: ________________

Depth: ____________________ Time: ________________

Question #	Problem	Answer	Question #	Problem	Answer
1	34 + 5 • 5		25	55 – 5 • 5	
2	45 – 5 • 5		26	24 + 6 • 2	
3	78 + 6 • 6		27	36 – 4 • 3	
4	46 + 4 • 2		28	60 + 2 • 6	
5	48 – 7 • 4		29	95 – 1 • 4	
6	21 – 3 • 6		30	54 + 3 • 9	
7	25 + 2 • 3		31	69 + 7 • 7	
8	36 + 5 • 9		32	45 – 9 • 6	
9	28 – 2 • 7		33	24 – 8 • 5	
10	48 – 1 • 8		34	15 + 7 • 4	
11	96 - 9 • 2		35	63 + 6 • 3	
12	47 + 6 • 4		36	84 – 2 • 1	
13	65 – 7 • 6		37	25 – 4 • 5	
14	95 + 5 • 1		38	78 + 5 • 9	
15	14 + 4 • 5		39	94 + 6 • 7	
16	25 + 6 • 9		40	58 – 8 • 8	
17	32 – 3 • 3		41	54 – 7 • 4	
18	24 – 2 • 2		42	29 – 9 • 3	
19	50 + 5 • 1		43	65 + 6 • 1	
20	61 – 7 • 9		44	41 + 1 • 5	
21	97 + 6 • 6		45	18 – 7 • 4	
22	36 + 5 • 4		46	32 + 6 • 6	
23	24 – 6 • 2		47	45 + 3 • 5	
24	21 – 1 • 9		48	79 – 1 • 7	

3. Samples Matrices from the Matrices Drawing Test





4.

4. Sample Number Pairs from the Number Comparison Test (S=Same, D = Different)

SUBJECT_____														
DATE_______														S OR D
DEPTH_____														
TEST #______														
	4	2	6	8	3	7		4	1	3	8	0	3	
	4	2	2	9	2	5		4	2	2	9	2	5	
	0	6	8	4	6	8		9	9	8	5	9	9	
	1	8	5	7	5	3		1	8	5	7	5	3	
	0	1	7	2	8	4		9	3	9	9	4	8	
	3	7	1	3	1	8		3	7	1	3	1	8	
	9	1	0	5	7	7		9	1	0	5	7	7	
	4	5	3	8	4	3		3	0	1	8	9	2	
	2	1	1	7	6	0		9	3	9	9	4	6	
	7	7	8	5	3	7		1	5	9	8	4	6	
	1	3	1	7	8	9		1	3	1	7	8	9	
	9	5	1	3	6	4		9	5	1	3	6	4	
	7	2	3	8	8	1		7	2	3	8	8	1	
	7	0	5	9	7	1		7	0	5	9	7	1	
	8	7	6	2	1	9		7	9	5	5	6	2	
	5	7	1	6	4	5		9	2	6	4	7	4	
	2	6	9	9	5	1		2	6	9	9	5	1	
	5	5	3	3	1	4		5	5	3	3	1	4	
	3	1	5	4	9	6		3	1	5	4	9	6	
	1	0	0	0	5	5		2	9	5	6	1	3	
	3	7	9	7	9	9		3	5	6	1	7	6	
	7	6	7	8	4	7		7	6	7	8	4	7	
	1	2	4	8	0	7		1	2	4	8	0	7	
	4	4	5	3	6	2		4	4	5	3	6	2	
	4	3	1	3	9	8		4	3	1	3	9	8	
	1	2	3	1	2	2		7	9	6	7	8	2	
	1	2	5	8	6	2		1	2	5	8	6	2	
	8	8	2	9	8	1		2	8	9	10	3	3	
	1	5	3	2	6	5		1	5	3	2	6	5	
	7	8	7	7	4	8		1	7	8	9	3	8	
	8	4	2	9	7	9		8	4	2	9	7	9	
	3	0	9	8	0	9		3	0	9	8	0	9	

5. Sample of Recognition Memory Test

Name: ______________________ Date: __________________ N_2O / Air

Condition A Part 1

3 minutes to look at and remember list of 16 words.

FROG

DISK

YACHT

GRAM

MILK

HYMN

JEWEL

EARTH

FACT

SPOON

CHEER

BOWL

CAKE

FATE

SCAB

HINGE

5. Sample of Recognition Memory Test continued

Name: ______________________ Date: ____________________ N_2O / Air

Condition A – Part 2. Five minutes to circle as many of the original 16 words as possible. Only 16 circles allowed

FROG	PLATE	HYMN	WING	STORK
FACE	GRILL	SPARK	BRICK	PEST
DRUM	YACHT	SUITE	ZEST	SLEEP
HELM	TEST	YARD	PUNT	SLAT
DISK	FOAM	JEWEL	GRADE	SHIN
SLAT	RAIN	SWAMP	WHEEL	CHEER
WIMP	EARTH	CHANT	SHIN	COLT
LAMP	HAND	ACHE	BELT	DENT
SWAB	TRUCK	PURSE	DOVE	BLISS
GROOM	GLOSS	GOOSE	BOWL	EARTH
MONK	GRAM	PASTE	CORN	SCAR
FACT	PLUM	BOOM	SINK	PARK
DRUG	MONK	WEED	HEFT	HINGE
CHAISE	MOUSE	MILK	CAVE	MONK
GROVE	YOUTH	ROOK	SPOON	DRUM
CAKE	FATE	COLT	HOOD	HATCH
DOPE	MILE	SINK	FISH	SCAB
FONT	WITCH	MILE	HACK	COMB
PARK	SHIN	SEAL	DEBT	ARCH
DICE	COLT	HEFT	GOAD	HALL