CHRONIC COGNITIVE EFFECTS OF DIVING ON SPORT AND RESCUE DIVERS

BY

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PREFACE

The study described in this dissertation was conducted in the School of Psychology, University of Natal, Pietermaritzburg, under the supervision of Mr. Douglas Mansfield. It represents original work by the author, and has not been otherwise submitted in any form for a degree or diploma to any university. When use has been made of the work of other authors, it is acknowledged in the text.

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Date...15/10/02...

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ABSTRACT

There has been much debate about whether shallow water diving, in the absence of neurological insult, can lead to cognitive deficits. The aim of this study was to investigate possible neuropsychological effects on two groups of divers, without any known history of decompression illness, who represent opposite ends of the spectrum of diving practice (rescue divers and sport divers), and to compare them with a non-diving control group. 17 rescue divers, 17 non-diving controls and 15 sport divers were recruited. The groups were matched for age, but not for education. The two diving groups were comparable in terms of diving history. Results of neuropsychological testing indicated that the rescue diving group was not significantly different from the control group, suggesting that rescue diving under controlled conditions is comparatively safe. The sport diver group performed significantly worse than controls on a test of verbal reasoning (Comprehension, SAWAIS-R) and on a measure of word fluency (Controlled Oral Word Initiation Test), suggesting the possibility that risky diving practices may lead to decrements in frontal lobe functioning. Another possibility is that global decrements occur, but that the tests of frontal lobe functioning were more sensitive to mild deficits in functioning. This contention is tentative, and further research into frontal lobe functioning of divers should be conducted. Sport divers are recommended to follow safe diving practices and use dive profiles that avoid bubbling in order to prevent cognitive damage.

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CHAPTER 1: RATIONALE AND PURPOSE OF THE STUDY

The purpose of this dissertation is to examine the chronic cognitive effects of diving on rescue and sport divers, and to ascertain whether there are any differences between these two groups and a non-diving control group. Scuba (self-contained underwater breathing apparatus) diving is rapidly gaining popularity, therefore it is important to ascertain whether the current legislation regarding safe diving practice is associated with any cognitive damage.

Recreational diving has become an extremely popular sport, attracting thousands of new participants every year. Rescue diving is an essential part of emergency services in order to recover people from drowning incidents. These two types of diving differ in the risk factors involved, and in the precautionary measures taken in order to ensure safe diving practice, but both involve the potentially hazardous practice of breathing compressed air under pressure.

The rationale for contrasting these two particular groups of divers is that they are positioned on opposite ends of a continuum of diving practice. The rescue divers are representative of a population of divers who follow safe diving practices and are physically fit. Sport divers are generally a group that display more risky diving behaviour, including making repetitive dives, consuming alcohol prior to and after diving, and not adhering to the dive tables. Existing literature is scarce and methodologically flawed, and the contention that diving causes cognitive damage is a controversial one.

While a great deal of research has investigated the effect of decompression illness on cognitive functioning, there is very little reliable information on the cognitive effect of diving without a history of decompression illness. Such effects may not be physiologically detectable, and the diver may not be consciously aware of any symptoms, however they may be manifested as subtle cognitive deficits that can be identified and measured by means of objective neuropsychological tests. It is thus the purpose of this research project to investigate potential chronic cognitive impairments in asymptomatic rescue and recreational scuba divers without a history of DCI.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This chapter will explain the physiological effects of diving, including the relevant gas laws and the aetiology and consequences of decompression illness. The cognitive effects of diving will be explained in the context of the different types of diving practice. The neuropsychological research on diving will be discussed, and the tests commonly used will be indicated. Finally, weaknesses of previous research will be elaborated.

The human body is poorly adapted to function underwater, since the air cavities in the body are vulnerable to injury from pressure (Schwerzmann et al., 2001). In order to prevent injury, divers equalise the pressure in the air cavities with the increased external ambient water pressure by breathing from self contained underwater breathing apparatus (scuba) that deliver compressed air at a pressure equal to the ambient water pressure. However, the increased partial pressure of the gas can lead to toxic effects and bubble formation (Lunn, 2001). Bubbles can form following dives to seven metres, and can result in direct damage or ischaemia (Lunn, 2001).

Although there are other fields in which hyperbaric exposures (elevated pressure) occur, including underwater archaeology, construction and tunneling projects, hyperbaric oxygen treatment facilities and aviation, the most common type of hyperbaric exposure is recreational scuba diving due to its growth in popularity (Campbell, 2002). There has been increasing concern over the potential chronic detrimental effects of diving

(Campbell, 2002; Todnem et al., 1991; Tetzlaff et al, 1999; Bast-Pettersen, 1999). This study is concerned with the possible chronic cognitive effects on the entire population of divers, and also with any differences in susceptibility by the two selected diving populations.

2.2.Physiological Effects of Diving

At sea level, the body is exposed to one atmosphere (ATA) of pressure from surrounding gases. For every 33 feet (approximately 10 metres) that a diver descends, this pressure increases by one ATA. Diving air is composed of approximately 79% nitrogen and 21% oxygen (U.S. Navy Diving Manual, 1993). Nitrogen is an inert gas that has no effect on an individual at normal pressure, however with increased depth, it begins to affect the body physiologically (The NAUI Textbook, 1985).

2.2.1 Gas Laws

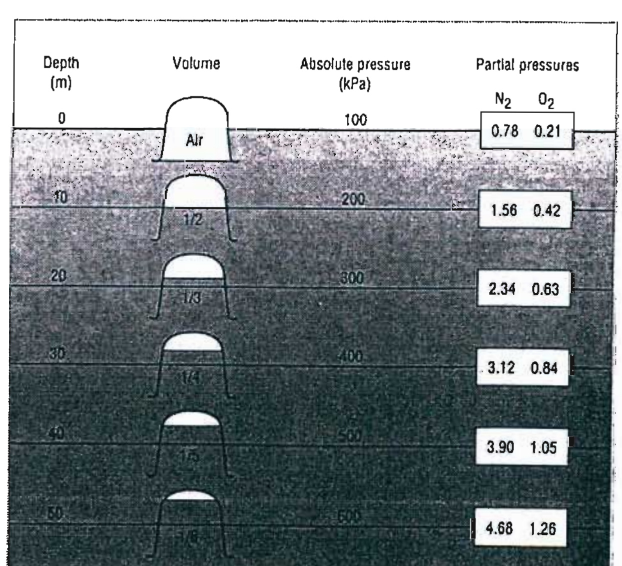
Gases are subject to changes in pressure, temperature and volume. The effect of changing pressure is particularly important to the diver because they are exposed to increased pressure when under water. The important laws are as follows (U.S. Navy Diving Manual Volume 1 (Air Diving), 1993):

(1) **Boyle's Law.** This law states "for any gas at a constant temperature, the volume of the gas will vary inversely with the pressure" (U.S. Navy Diving Manual, 1993, p. 14;

depth and volume. This means that as a diver descends, air becomes compressed, and with ascent, the air expands. These changes in volume are in proportion to changes in absolute pressure, so the most pronounced changes will be within 10 metres of the surface. This means sudden changes of depth in shallow water are more hazardous than equivalent changes in deeper water.

(2) **Dalton's Law.** This law states "the total pressure exerted by a mixture of gases is equal to the sum of the pressures of the different gases making up the mixture, with each gas acting as if it alone was present and occupied the total volume" (U.S. Navy Diving Manual, 1993, p.19). In a gas mixture, the part of the total pressure contributed by a single gas is called the partial pressure of that gas. Air at sea level consists of approximately 80% nitrogen and 20% oxygen (Kayle, 1994). The partial pressure of some gases is small at atmospheric pressure, but increases significantly at higher pressures.

Figure 1: Effect of depth on partial pressures of nitrogen and oxygen



Wilmshurst (1998, p. 996)

(3) **Henry's Law.** This law states "the amount of any given gas that will dissolve in a liquid at a given temperature is a function of the partial pressure of that gas in contact with the liquid and the solubility coefficient of the gas in the particular liquid" (U.S. Navy Diving Manual, 1993, p. 22). As the human body is made up largely of water, this law states that with increased depth and pressure, more gas dissolves in the body tissues, and must be released on ascent (Kayle, 1994).

Gas molecules diffuse into the tissues of the body along a pressure gradient. At sea level (1 ATA), the tissues of the body are equilibrated with nitrogen at a partial pressure equal to the partial pressure of nitrogen in the lungs. With exposure to increased pressure during diving, the partial pressure of nitrogen in the lungs will change, and tissues must either eliminate or absorb nitrogen to reach a new equilibrium. If a diver breathes a gas for long enough, no further diffusion of the gas will take place. The tissue is then termed saturated.

With descent, increased pressure causes more nitrogen to enter the body's tissues. The gas dissolved in a diver's body will remain in solution as long as pressure is maintained. With ascent and a concomitant decrease in pressure, the dissolved gas will begin to come out of solution. In a controlled ascent (using the decompression tables), this gas is carried to the lungs and exhaled before it accumulates sufficiently to form bubbles in the tissues. However, with sudden ascent, bubbles may form and lead to decompression illness. (Campbell, 2002; Strauss and Yount, 1977; Kayle, 1994).

2.2.2. Decompression

Decompression is the process whereby excess inert gas (particularly nitrogen) absorbed during increased pressure is expelled by the lungs when pressure is reduced with ascent (Kayle, 1994). Dissolved gas is circulated through the body by the capillaries, and diffuses into the tissues (Moon and Vann, 1995). Tissue uptake and release of a gas depends on several factors, including solubility of the gas in a tissue, blood supply to the tissue, time, dive depth, temperature and the gas gradient (Kayle, 1994). Diffusion of gases into and out of the brain and spinal cord is quick due to the large number of capillaries in these tissues. They are known as 'fast' tissues (Moon and Vann, 1995), and the potential for nitrogen bubbling in these tissues is greater.

The purpose of decompression using the decompression tables is to establish a gentle gas gradient to avoid the formation of bubbles and prevent decompression illness (Kayle, 1994). For most air dives, the rate of ascent should not exceed 15 metres per minute (Wilmshurst, 1998).

2.2.2.1. *Decompression Illness*

Decompression illness (DCI) is caused by the formation of gas bubbles in the blood and body tissues with the reduction of ambient (surrounding) pressure (Strauss and Yount, 1977). When a diver descends, the increased pressure in the water results in nitrogen from air in the lungs diffusing into solution in blood and tissues. According to Henry's law, if pressure is suddenly reduced, the nitrogen will rapidly return to its natural state (gas), and form bubbles (Telford, 1990). Decompression illness may occur if nitrogen bubbles form as a result of a large amount of stored nitrogen combined with a swift ascent.

DCI may also result from repetitive dives in which the residual nitrogen time is not included in the next total dive time, resulting in nitrogen overload (Kayle, 1994). The practice of repetitive diving results in residual nitrogen remaining in the body tissues of the diver for 24 hours or more, which has the effect of shortening the permitted exposure time for any subsequent dive deeper than 2 ATA (Workman and Bornmann, 1975). The dive tables make provision for repetitive diving by specifying the permitted depth and duration of subsequent dives (U.S. Navy Diving Manual, 1993).

Moon and Vann (1995) have estimated that in recreational divers worldwide, there is one incident of DCI per 5000 to 10000 dives. For commercial divers, who encounter higher pressures for longer periods, the rate of DCI is increased to one incident per 500 to 1000 dives.

Decompression illness was originally referred to as decompression sickness (DCS), and was classified into DCS I, which involved musculoskeletal pain, and DCS II, which included symptoms from the nervous, respiratory and circulatory systems (Elliott and Kindwall, 1982, cited in Todnem, Nyland, Kambestad and Aarli, 1990). Symptoms of Type II DCS were considered to be less immediately and unequivocally apparent as those of Type I DCS, therefore it was of concern that divers may attribute them to overexertion and fail to report them (U.S. Navy Diving Manual, 1993). Dick and Massey (1985) suggested that both divers and their doctors ignored mild symptoms of DCS because they expected neurological symptoms to be severe. Kayle (1994) added that divers tended to disregard the possibility of DCS due to their adherence to safe dive protocol, but failed to take into account the possible effect of other risk factors.

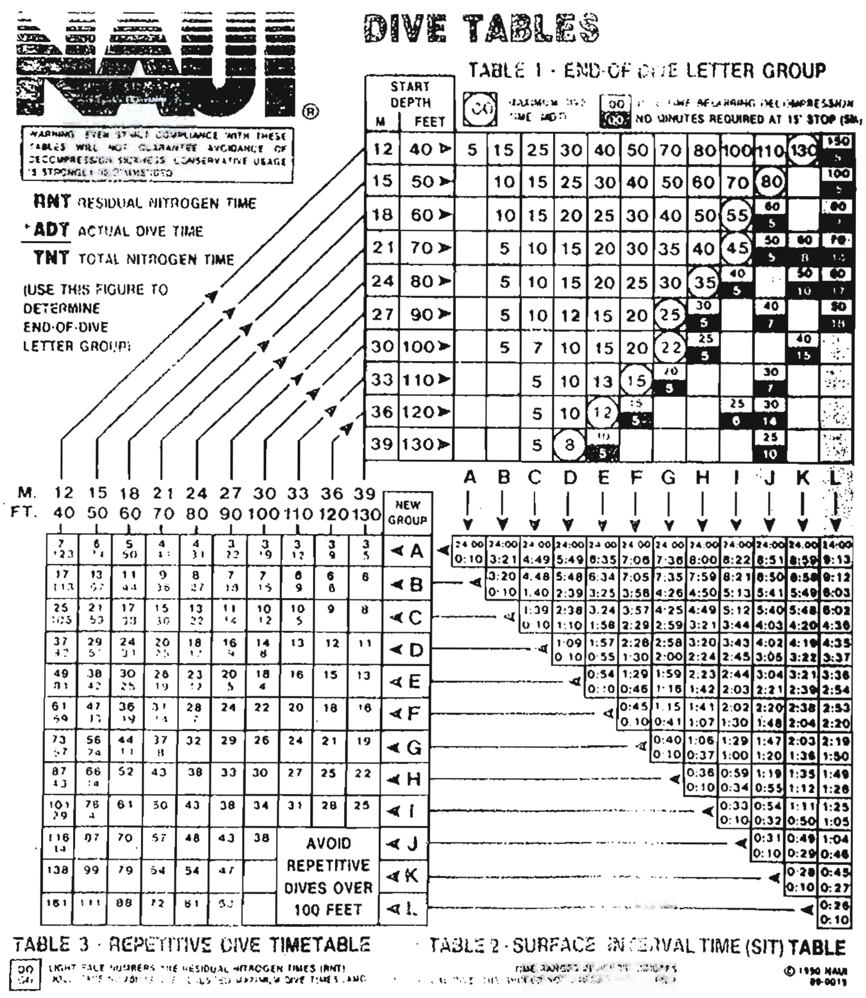
This classification system was questioned because the distinction between the two types of DCS were regarded as spurious, coexistence of symptoms occurred, and Type I DCS was known to frequently progress to Type II DCS (Francis, Smith and Sykes, 1990; Kayle, 1994). The classification was consequently abandoned in favour of the term decompression illness (DCI) (Frances, Smith and Sykes, 1990; Kayle, 1994), which encompasses DCS I, DCS II and arterial gas embolism. However, since much of the research was conducted prior to the change in classification, the research reported in this study will frequently refer to the previous classification system.

Arterial gas embolism (AGE) is considered to be the most serious potential consequence of diving (U.S. Navy Diving Manual, 1993). AGE is caused by excess pressure inside the lungs that is not vented on ascent, resulting in rupturing blood vessels in the lungs, leading to bubbles being carried into the heart and pumped into the arteries. Any bubble that is too large to pass through an artery will lodge and form an embolus, depriving the tissue of blood and oxygen. The consequences depend on the area or organ where the blockage occurs. (Moon and Vann, 1995). Gas bubbles in the cerebral arteries are termed Cerebral Arterial Gas Embolism (Telford, 1990).

In order to avoid DCI, divers reduce pressure gradually by stopping at recommended points on their ascent for varying periods, depending on the depth of their dive and the length of time that they spent there. The decompression stops allow nitrogen to diffuse from the tissue into the lungs where it can be exhaled without forming bubbles. However, Moon and Vann (1995) have indicated that divers who claimed to have been diving within specified decompression limits suffer 50% of cases of decompression illness. The authors suggested that a slower rate of ascent (nine, rather than 18, metres per minute) has been demonstrated in animal studies to be safer and produce fewer bubbles. The authors also indicated that in dives that do not require decompression stops, a "safety stop" of several minutes at a depth of five or six meters could be added. The authors quoted research by the Divers Alert Network, which showed that a three-minute safety stop at six meters reduced venous bubbles by 50 percent (Moon and Vann, 1995). These safety measures might allow rapidly exchanging neurological tissues sufficient time to eliminate excess inert gas, reducing the degree of supersaturation and the possibility of bubble growth (Moon and Vann, 1995).

The dive tables and computer algorithms that are commonly used in South Africa to avoid DCI are based on the U.S. Navy dive tables (1993). An example of a typical dive table is presented on the following page.

Figure 2: A dive table commonly used in South Africa



2.2.2.2. *Symptoms of DCI*

Symptoms of DCI may occur immediately after decompression, or may show a delayed presentation due to the growth of bubbles from small and silent to large and painful, or the process of swelling following tissue damage (Hempleman, 1975; Strauss and Yount, 1977; Warren et al., 1988). The presentation of symptoms depends on the tissue or organ involved (Kayle, 1994).

Damage following decompression illness has been noted in various organ systems, including the brain, spinal cord, retina, inner ear and lungs (Campbell, 2002). Other studies have suggested decrements in pulmonary and cognitive functions (Campbell, 2002; Calder, 1992). Lunn (2001) has indicated that brain damage resulting from DCI can manifest as either focal deficits or global impairment, and has similar consequences to brain injury due to other causes.

In severe cases of DCI, which resulted in death, bubbles have been reported throughout the organism (Strauss and Yount, 1977). Bubbles cause the obstruction of blood flow in small vessels, depriving tissue of nutrients and oxygen and leading to damage or death of the tissue. They may also cause capillaries to leak, resulting in the blood becoming more viscous (Strauss and Yount, 1977). Calder (1992) termed the damage to blood vessels Virchof's Triad, and indicated that it is "caused by changes in blood components, blood flow or intimal damage" (p. 214).

Neuropsychological testing has indicated that 90% of commercial divers with a history of DCI affecting the central nervous system had abnormal scores compared with commercial divers with no history of DCI (Peters, Levin and Kelly, 1977). Todnem et al. (cited in McQueen, Kent and Murrison, 1994) have suggested that an episode of DCI is a risk factor for the subsequent development of neurological symptoms in individuals who continue to dive. McQueen, Kent and Murrison (1994) affirmed that continued diving after DCI is associated with increased psychiatric morbidity (particularly symptoms of depression) and neurological symptoms.

2.2.2.3. *Susceptibility to DCI*

The most common causes of DCI are rapid ascent in an emergency situation and marginally adequate decompression (Strauss and Yount, 1977). However, DCI may occur from dives that required no decompression, or when decompression procedures were followed meticulously (U.S. Navy Diving Manual, 1993). Dick and Massey (1985, cited in McQueen, Kent and Murrison, 1994) suggest that there are individual differences in susceptibility to DCI, probably as a result of undefined somatic or environmental factors.

Susceptibility appears to be related to several physical factors, including:

(1) Obesity. Fat holds five times more nitrogen than blood or muscle tissue (U.S. Navy Diving Manual, 1993; Kayle, 1994), and nitrogen is excreted slowly from fatty tissue due to relatively poor circulation.

(2) Exertion. Greater blood circulation delivers more nitrogen into the tissues, as well as producing more carbon dioxide, which promotes bubble development and growth (Kayle, 1994)

(3) Age. With increased age there is a tendency towards an increase in body fat as well as arteriosclerosis (Kayle, 1994), which increases the amount of nitrogen absorption and leads to narrowing of the blood vessels.

(4) Cold. This promotes the absorption of inert gas, and also reduces circulation, leading to a slower return of nitrogen to the lungs for elimination (Strauss and Yount, 1977; Kayle, 1994)

(5) Heat following ascent. This leads to swift degassing, which can cause bubble formation even with adherence to the ascent schedule (Kayle, 1994).

(6) Dehydration during and following a dive. This leads to less available liquid, and consequently faster saturation of the remaining fluid (Kayle, 1994).

(7) Injury. This causes tissue swelling, resulting in slower degassing and the potential for bubble formation (Strauss and Yount, 1977; U.S Navy Diving Manual, 1993; Kayle, 1994).

(8) Alcoholic hangover. This influences susceptibility to DCI due to dehydration (Kayle, 1994). A Divers Alert Network (DAN) report has estimated that 50% of DCI cases were alcohol-related (Kayle, 1994).

(9) Gender. Women have more fatty tissue, so have a greater potential to store nitrogen, and are theoretically at higher risk for DCI (Kayle, 1994).

(10) Smoking. This leads to decreased permeability of the alveolar walls, leading to reduced oxygen uptake and inefficient elimination of carbon dioxide and nitrogen (Kayle, 1994).

Kayle (1994) has suggested that a combination of factors is likely to be responsible for onset of DCI following a technically safe dive. Prevention of DCI requires avoidance of the predisposing factors, as well as adequate hydration (Ibid.).

2.2.2.4. *Treatment of DCI*

Decompression illness is treated by recompression. The diver is placed in a hyperbaric chamber, and the air pressure is increased. The increased pressure causes the bubbles to diminish in size, and the diver breathes pure oxygen in order to increase the diffusion gradient of inert gas out of the body (Strauss and Yount, 1977; Dick and Massey, 1985; Kayle, 1994). Treatment can be effective if administered timeously, but once tissue damage has begun to occur, recovery following recompression will not be complete (Kayle, 1994).

2.2.2.5. *Prognosis Following DCI*

Recovery after CNS decompression illness is good, but Roszahegyi (1959) has reported that in 75% of serious cases there remain subjective and objective signs, indicating lasting damage to the tissue. DCI of the central nervous system is considered to be extremely serious, and complete recovery is unlikely. Roszahegyi (1959) argued the best form of treatment for DCI was prevention.

2.3. Cognitive Damage in Divers

Gas nucleation does not always lead to decompression sickness (Wilmshurst, 1997). Doppler ultrasound studies have revealed that "silent" bubbles exist in the blood of many asymptomatic divers (Behnke, 1975; Wilmshurst, 1997), and Elliott and Hallenbeck (1975) have indicated that bubbles form in almost every decompression. In addition, Walder (1975) reported that bone damage and subtle biochemical effects occur despite adequate decompression.

Wilmshurst (1997) has suggested that decompression illness is on a continuum, which raises the possibility that divers without a history of clinically detectable DCI could display cognitive deficits due to the development of subtle lesions (Elliott, 1989; Wilmshurst, 1997). This contention was supported by Peters, Levin and Kelly (1977), who found that DCI caused diffuse and multiple CNS lesions in a group of divers. A study by McQueen, Kent and Murrison (1994), that found that in divers with no history of DCI, the frequency of diving was associated with reports of neurological symptoms.

Bennett (1994, cited in Bast-Pettersen, 1999) has suggested that there is a lack of information on potential pathology that may occur without overt signs of DCI. There have been five international meetings since 1978 to discuss the possibility of neurological damage without a clear precipitating event (such as DCI), but no consensus has been reached regarding whether diving causes brain damage (Wilmshurst, 1997; Cordes et al., 2000).

Calder (1992) warned of the " 'iceberg' phenomenon of hidden damage" (p. 213), and suggested that subtle damage to the brain may occur without the presence of overt clinical signs. The author added that this erosion into the reserves of the brain might become significant for divers as they age, due to the natural process of degeneration of the brain. Calder (1992) emphasised the need to develop methods for clinical identification of subtle changes. In the light of the accumulating evidence of subtle damage to the CNS, Calder (1992, p. 214) suggested that poorly controlled diving could be regarded as "knowingly putting health at risk".

Calder's (1992) contention of subtle damage has been supported in research (Shuttleworth-Jordan, 1999) into the effects of cumulative mild head injury on rugby players. The study used the theory of brain reserve capacity (Satz, 1993, in Shuttleworth-Jordan, 1999) to explain how clinical presentation of symptoms varies according to "education, intelligence, sex, age and additional cerebral insult" (p. 284). This is applicable to diving because repeated subclinical damage by bubbles in the CNS may lead to cumulative damage in the long term, and may also become evident as the brain ages.

However, Elliott (1989) has argued that deficits due to deep diving are transient. He quoted the conclusion of a conference in 1983 into the long-term neurological sequelae of diving that "there was no evidence of permanent neurological damage due to deep diving" (p. 80). He contended that histopathological findings are only relevant if they impact on quality of life of the diver. Elliott distinguished between detectable effects, which are outside the normal range for the population, and detrimental effects, that adversely affect the individual's quality of life (Elliott, 1997). He acknowledged that a detectable effect might become detrimental at a later stage.

Elliott (1989, in Campbell, 2002) has pointed out that "in spite of much detailed investigation, no special investigation has yet demonstrated a deficit which is of sufficient concern to change current standards of fitness to continue diving in healthy divers who have had no decompression incident" (p. 6).

Investigations into the chronic effects of diving have focussed on different types of divers, because all share the common feature of breathing air under pressure. It is widely believed that the differences in these groups of divers are of degree rather than kind (Campbell, 2000), with the saturation and commercial divers showing greater deficits due to the larger number of dives completed.

2.3.1. Cognitive Damage in Saturation Divers

The majority of investigations into the consequences of diving have focussed on the effects of saturation diving (Vaernes, Klove and Ellertsen, 1989, cited in Campbell, 2002; Todnem, Nyland, Kambestad and Aarli, 1990; Todnem et al., 1991; Fueredi, Czarnecki and Kindwall, 1991). Saturation diving is of interest as the divers accumulate many diving hours; therefore any deficits due to diving would be more likely to be apparent in this population.

2.3.1.1. *Characteristics*

Saturation diving refers to the practice of divers remaining at a given pressure for several days in a pressure chamber. After approximately 12 hours at a given pressure, the diver's body is saturated with inert gas, enabling the diver to remain under pressure for extended periods without additional decompression time (Workman and Bornmann, 1975; Strauss and Yount, 1977; Curley, Berghage, Raymond and Sode, 1979).

Saturation diving is usually undertaken during the building of tunnels under water or on marine oilrigs, and the divers are lowered to the work site on a diving bell that can be detached from a larger chamber. Saturation diving differs from amateur diving in the breathing of a helium/oxygen mixture, as well as differing depth, duration and decompression mode (Reul, Weis, Jung, Willmes and Thron (1995).

2.3.1.2. *Research*

Rozsahegyi (1959) was the first to identify a potential association between decompression illness and neurological and cognitive change when he reported clinical observations on caisson workers. He studied 100 subjects with Type II DCS, and found that 75% of the subjects had symptoms and objective signs between two and a half and 5 ½ years later. Of particular interest was his finding that many of his subjects displayed personality changes, including irritability and uncontrollability.

Todnem et al. (1991) studied 40 commercial saturation divers (of which 65% had suffered DCI) one to seven years after their last deep dive (190-500 metres of seawater). The authors found that divers had more CNS symptoms than controls, the most prominent symptom being concentration difficulty. Divers also displayed more abnormal neurological symptoms. The neurological symptoms were significantly correlated with previous episodes of DCI, exposure to saturation diving, total diving, deep diving and air diving. Abnormal findings in the neurological examination were significantly correlated with exposure to air diving, total diving, saturation diving, and deep diving, DCS I and DCS II, and age. Divers also had more abnormal Electroencephalograms, suggesting neuronal dysfunction that may have contributed to cerebral dysfunction

Todnem et al. (1991) concluded that deep diving could have a long-term effect on the nervous system. The authors added that divers who have had DCS II have an increased risk of further neurological symptoms, and divers with a long exposure to saturation diving have increased risk of neurological symptoms, even in the absence of DCS II. However, the authors cautioned that the deep divers had also performed ordinary saturation diving, as well as air diving, making interpretation of the results difficult.

Vaernes, Klove and Ellertsen (1989, cited in Campbell, 2002) compared deep saturation divers with experienced divers just beginning saturation diving, and found mild to moderate neuropsychological changes, consisting of increased tremor and reduced spatial memory, vigilance and autonomic reactivity in 20% of the saturation divers after deep dives. Only the vigilance test results improved one year later. They concluded that repeated deep diving (classified as more than 180 metres of seawater) could lead to pronounced neuropsychological impairment. The authors found a correlation between the presence of frontal periventricular white matter lesions and cognitive change (Vaernes, Klove and Ellertsen, 1989, in Lunn, 2001).

Todnem, Nyland, Kambestad and Aarli (1990) compared a group of air and saturation divers (of which 85% were saturation divers, and 51% had a history of DCS) with a group of non-diving controls. They found that the divers had significantly more symptoms from the nervous system, and more abnormal neurological findings. They reported that the most prominent symptoms were concentration and memory difficulties. These symptoms were independently significantly correlated with diving exposure, prevalence of DCS and age. They found that neurological symptoms were significantly correlated with both DCS I and DCS II, and suggested that both types of decompression sickness may lead to neurological dysfunction.

Fueredi, Czarnecki and Kindwall (1991) studied a group of compressed air tunnel workers without a known history of DCI, using magnetic resonance imaging and psychometric testing. They found that caisson workers have a much higher risk than matched control subjects of sustaining cerebral injury. Although there were no significant differences in the psychometric results, the authors reported that caisson workers performed worse than the control subjects on all of the tests.

Lunn (2001) has commented that despite extensive research in this area, there is no consensus on the chronic consequences of saturation diving on cognitive function. The author indicated that anecdotal reports describe gradual personality change, decreased impulse control, irritability, decreased alcohol tolerance and forgetfulness. The research in this area is flawed due to the inclusion of heterogeneous groups of divers (some who had suffered from DCI, and others who had not).

2.3.2. Cognitive Damage in Commercial Divers

In the past, it was believed that shallow divers differed from saturation divers in that any CNS damage was restricted to the spinal cord (Lunn, 2001). However, it is currently believed that cognitive damage can occur in these divers due to CNS demyelination (Calder, 1992).

2.3.2.1. *Characteristics*

In order to qualify as a professional diver in South Africa, individuals are required to pass a stringent medical examination, and thereafter register with the Department of Manpower as a learner diver and complete a commercial diving course at an approved training centre (Bouch, 1989). These divers are likely to adhere to the dive tables as a condition of employment, and undergo compulsory neurological examinations annually.

Cordes et al. (2000) indicated that commercial divers are exposed to "carefully controlled diving" (p. 1745). Bast-Pettersen (1999) indicated there is a "healthy worker effect" (p.

55) in commercial divers, since only divers who are healthy remain in the profession. Therefore, studies on commercial divers may not provide a reliable indicator of the cognitive effects of diving on sport divers.

There is limited literature on the relationship between prolonged breathing of compressed air and permanent intellectual impairment (Campbell, 2002). Most studies that have been undertaken have focussed on the effects of DCI on commercial divers.

2.3.2.2. *Research*

Roszahegyi and Roth described chronic neuropsychological changes in commercial divers in 1966 (Calder, 1992). Further evidence has subsequently been advanced to support this conclusion (Smyth, 1985; Todnem et al., 1990). According to Calder (1992, p. 213), manifestations include "memory loss, aggressive or antisocial behaviour, retarded reaction time, tiredness, inability to concentrate or communicate, visual difficulties, loss of interest in personal appearance and low tolerance of alcohol".

Peters, Levin and Kelly (1977) compared a group of commercial divers who had suffered decompression illness (DCI) with a group of divers who had not. They found that the group who had suffered DCI manifested neuropsychological impairment on tests of memory and psychomotor speed, and showed greater "distress, depression, anxiety, somatic concern and disruption of cognitive efficiency" (p. 126). Vaernes and Eidsvik (1982, cited in Campbell, 2002) supported this association in compressed air divers with decompression sickness, but this study was restricted to subjects who had neurological DCI.

Morris, Leach, King and Rawlins (1991, cited in Calder, 1992) conducted a large study of 282 professional divers (some of whom had a history of DCI) and 243 controls, and found evidence of cognitive impairment in the divers. The study reported a decline in short-term memory and non-verbal reasoning (Calder, 1992; Lunn, 2001). However, this study is problematic due to the inclusion of a heterogeneous group of divers.

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Dolmierski et al. (cited in Todnem, Nyland, Kambestad and Aarli, 1990) found that 30% of a group of air divers had abnormal neurological findings, although only half of them had suffered DCI.

One of the few studies of the long-term neuropsychological effects of shallow-water diving in commercial divers without a history of DCI was conducted by Bast-Pettersen (1999). She did not find evidence of clinical impairment, but noted that divers displayed a longer reaction time, which could be ascribed to diving. Bast-Pettersen's group was not matched for age, which may have confounded the results.

Tetzlaff et al. (1999) compared a group of elderly commercial compressed air divers without a history of decompression illness with non-diving controls, using MR studies and performance on neuropsychological tests. They found that the divers showed significantly poorer mental flexibility and visual tracking abilities. Furthermore, they found that poor performance in mental flexibility; visual tracking and immediate recall of verbal material were significantly related to years of diving. The researchers concluded that divers are at risk of detrimental long-term effects to the central nervous system.

A recent study by Cordes et al. (2000) compared a group of professional divers without a history of DCI to non-diving controls with respect to neurological, neuropsychological and neuroradiologic status. They concluded that there are no long-term CNS sequelae, provided that the diving is performed under controlled conditions. Although no significant neuropsychometric results were obtained, it is interesting to note that divers obtained significantly longer reaction times in the divided attention sub-test, and also showed significantly lower rates of recall on the fist trial of the memory test, as well as on the delayed recall trial. The authors pointed out that impairment of divided attention may be the earliest indicator of cortical dysfunction, and suggested that this may point to the effect of repeated diving.

2.3.3. Cognitive Damage in Sport Divers

Very few studies have been undertaken on the cognitive sequelae of sport diving. Studies that have been conducted have focussed on the effects of DCI (Dick and Massey, 1985; McQueen, Kent and Murrison, 1994), and on neurological examination (Warren et al., 1988; Holden, Morsman and Lane, 1992; Reul, Weis, Jung, Willmes and Thron, 1995) rather than neuropsychological assessment. This is presumably due to the belief that recreational divers are likely to be less severely affected than professional divers (Elliott, 1997). Elliott has stated that there are "no significant risks to the healthy diver" (1997, p. 16) that stays within the limits of the dive tables.

2.3.3.1. *Characteristics*

Sport divers are required to undergo a medical examination before commencement of diving, however, the requirements are not as rigorous as those for commercial divers (Telford, 1990). Scuba diving is not permitted without prior training, and the level of training dictates the depth to which the diver is allowed to dive. Most recreational divers are not permitted to dive below thirty metres, and new divers may not undertake dives to more than 18 metres (Venter, 1989).

2.3.3.2. *Research*

McQueen, Kent and Murrison (1994) studied the self-reported chronic effects of diving and DCI in recreational scuba divers. They suggested that recreational diving; both following DCI and with no history of decompression illness can result in neurological and psychological changes. However, the researchers acknowledged that their reliance on self-report data and the possibility of a response bias in the divers who responded to the survey was problematic.

Reul, Weis, Jung, Willmes and Thron (1995) compared amateur divers with no history of DCI with a non-diving control group. They found significantly more small hyperintense lesions in the brain and spinal cord of the divers. The authors suggested that these lesions might have been due to the occlusion of small blood vessels by gas bubbles, or of a vascular pathogenesis. They concluded that long-term amateur diving might cause CNS degeneration even in the absence of DCI. However, this study has been criticised by several authors (Wilmshurst, Edge and Bryson, 1995; Hovens, ter Riet and Visser, 1995), who have pointed out that a selection bias may have been operative since the divers who responded may have done so because they suspected that they had cause for concern.

There is evidence that certain individuals may be more susceptible to DCI than others (Dick and Massey, 1985), some sport divers sustaining injury in less than half the time allowed by the dive tables. The authors indicated that in many cases, dive-related causes of the accidents were not apparent, and that the divers in question had been diving responsibly. They concluded, "no amount of caution can completely eliminate the recognised small risk of occasional decompression injuries" (Dick and Massey, 1985, p. 670), a sentiment echoed by the U.S. Navy Diving Manual (1993). The variation in response may be due to undefined environmental or somatic variables.

Baskett (2000) conducted a study on recreational scuba divers without any history of DCI to determine whether diving practice and medical history was related to cognitive functioning. The author found scattered negative cognitive changes associated with diving practice, but cautiously concluded that recreational diving was safe.

2.3.4. Cognitive Damage in Skin Divers

2.3.4.1. *Characteristics*

Skin divers, spear fishermen and abalone divers are shallow divers who accumulate a large number of hours, and who frequently ignore the safety dive-protocols and decompression procedures (Andrews et al., 1986). In addition, these divers tend to suffer from hypoxia and carbon monoxide poisoning (Ibid.). They are considered to be of particular relevance because if there are any chronic adverse effects of shallow water diving, they should become apparent in this population first due to the risk factors mentioned above.

2.3.4.2. *Research*

Andrews et al. (1986) compared a group of abalone divers with a sample of fishermen, using neuropsychological tests. They found no evidence of cognitive impairment, and concluded that there was "no support for the theory that an accumulation of sub clinical neuropsychological insults can lead to a dementing process" (p. 401). However, the authors noted that the divers reported irritability, slowness and confusion after a hard days' diving, and that they performed less well than the fishermen on 5 out of 8 of the tests, although the results were not poor enough to suggest neuropsychological impairment.

Williamson, Clarke and Edmonds (1987) studied the neurobehavioural effects of abalone diving, and found that the abalone divers performed significantly worse than the controls in tests of learning and short-term memory. They also noticed a risk-taking approach to the test by the abalone divers, in that the divers sacrificed accuracy for speed on some of the tests. They concluded that there was impairment of nervous system function in abalone divers.

2.4. Discussion of Research

Many studies investigating neurological and neuropsychological impairment have included divers who have suffered from DCI (Todnem, Nyland, Kambestadt and Aarli, 1990; Todnem et al., 1991). It appears clear that DCI has a detrimental effect on cognitive functioning (Rozsahegyi, 1959; Peters, Levin and Kelly, 1977; Todnem, Nyland, Kambestadt and Aarli, 1990; Todnem et al., 1991). However, the cognitive effects of diving without a history of DCI have not been comprehensively researched (Lunn, 2001).

Postmortems on the brains of divers who had never suffered from DCI have revealed similar levels of degeneration and vasculopathy as those of divers with a history of decompression illness (Wilmshurst, 1997). Long-term damage to other organs has also led to a concern that the brain may be similarly affected by a diving history (ibid.). Furthermore, Wilmshurst, Edge and Bryson (1995) have suggested that since brain tissue is well-perfused, has a high fat content, has rapid uptake and elimination half-lives for nitrogen, and has a high nitrogen content when saturated, there is a greater potential for gas nucleation during decompression. The U.S. Navy Diving Manual (1993) indicates that nitrogen is five times more soluble in fat than in water.

Calder (1992) has suggested that neurological damage may occur "insidiously and without history of an acute incident" (p. 213), and postulated that there is a possibility of diffuse neurological damage that would not be revealed in investigations designed to reveal focal lesions. Calder (1992) also quoted a histological study (Palmer, Calder and Yates, 1982) that has produced evidence of diffuse damage to small cerebral vessels in both grey and white matter. The conclusion was that "these findings lead to proof positive that cerebral vasculopathy develops in divers" (p. 214). Calder suggested, "although damage may be neurologically diffuse, psychologically it appears to be localised" (1992, p. 213).

Yates (1997) has indicated that diving causes "direct local damage to brain tissue, ... permanent interruption of local vasomotor control and inadequate redistribution of blood to areas of the brain associated with thought" (p. 1761). Wilmshurst (1997) added "recurrent sub clinical decompression sickness may result in a condition analogous to a multi-infarct dementia with gas embolism ... as the initiator" (p. 689). Other authors (Todnem, Nyland, Kambestad and Aarli; 1990; Todnem et al., 1991; Reul, Weis, Jung, Willmes and Thron, 1995) also suggest that sub clinical episodes of DCI may lead to CNS damage with no symptoms, which may accumulate in the long term.

There is evidence of neuropathological change in the central nervous system (CNS) of some divers who, at the time of death, had no recorded incidence of DCI, and were considered fit to dive (Morild and Mork, 1994, and Palmer et al, 1990, cited in Campbell, 2002). Rozsahegyi (1967, in Fueredi, Czarnecki and Kindwall, 1991) reported that almost 50% of a group of caisson workers had abnormal electroencephalograms (EEG's) despite never having experienced DCI. Similarly, Gorman et al. (1986, in Fueredi, Czarnecki and Kindwall, 1991) reported that scuba divers who had been treated for pain-only DCI had abnormal findings on EEG, psychological tests and CT scans, despite normal neurological examinations.

However, at the 9th annual symposium on undersea and hyperbaric physiology, Edmonds and Hayward (1987, cited in McQueen, Kent and Murrison, 1994, p. 101) concluded, "a link between compressed-gas diving and neurological damage has yet to be established". To date there is no recognised syndrome associated with diving apart from acute decompression illness (Campbell, 2002).

Controlled data on chronic effects of diving without a history of DCI is lacking (Cordes et al., 2000). Recently, there have been several studies focusing on the neuropsychological effects of diving on commercial divers (Bast-Pettersen, 1999; Tezlaff et al., 1999; Cordes et al., 2000). Bast-Pettersen (1999) found no significant results, but suggested that an increased reaction time in the divers could be indicative of cognitive damage. Tetzlaff et al. (1999) investigated an older group of divers, and found significant results suggesting that divers are impaired on mental flexibility, visual tracking, and recall of nonverbal material, supporting Calder's (1992) contention of the "iceberg phenomenon of hidden damage" (p. 213). Cordes et al. (2000) investigated navy divers, and concluded that no neuropsychological deficits were found. However, this group would be likely to strictly adhere to the dive tables, which could have a protective effect against damage.

There appear to be no studies that have compared sport and commercial or rescue divers without a history of DCI.

2.5. Neuropsychological Functions Implicated in Diving Research

Research into the neuropsychological effects of diving is limited and methodologically flawed, as discussed below. The research that has been conducted has focussed on key areas that are believed to be affected by diving. The interest in neuropsychological research appears to have come about due to the failure of neurological tests to pinpoint areas of damage (Todnem et al., 1991; Cordes et al., 2000). Instead, Sedgwick, Murrison and Carr (1994, cited in Bast-Pettersen, 1999) have suggested that cumulative sub-clinical damage may manifest as psychological, rather than neurological, disturbance.

The Diver Performance Research Unit at the University of Lancaster has suggested that professional divers aged 24 to 39 have marked deterioration in short-term memory and reasoning skills (Smyth, 1985; Monaghan, n.d.). The researchers attributed this decrement to continual compression and decompression. The authors suggested that despite adequate decompression procedures, small bubbles may have formed, leading to minute lesions in the cortex, which may have had a cumulative effect on the brains of the divers (Smyth, 1985; Elliott, 1989; Calder, 1992; Sedgwick, Murrison and Carr, 1994, cited in Bast-Pettersen, 1999; Reul, Weis, Jung, Willmes and Thron, 1995). Brubakk (1994, cited in Tetzlaff et al., 1999) has suggested, "clinically silent gas microemboli may occur in small cerebral vessels due to decompression" (p. 197).

The literature (Smyth, 1985; Calder, 1992; Wilmshurst, 1997) has suggested that subclinical gas bubbles lead to global decrements in functioning; therefore most studies have administered a broad spectrum of tests encompassing the main areas of functioning. Tests used have varied in different studies, therefore it is often difficult to compare results since particular tests may be more sensitive to deficits than others, and may also measure slightly different aspects of the particular function. The neuropsychological function assessed and tests used are discussed below.

2.5.1. Immediate and Delayed Auditory Memory

Several authors (Peters, Levin and Kelly, 1977; Andrews et al., 1986; Williamson, Clarke and Edmonds, 1987; Tetzlaff et al., 1999; Bast-Pettersen, 1999; Cordes et al., 2000) have assessed memory. Most researchers have used the Wechsler Memory Scale (WMS) or some of its subtests (particularly the digit span and paired associates subtests). Tetzlaff et al. (1999) used Buhschke's Selective Reminding Test (SRT), which consists of a series of

12 unrelated words, presented over 12 selective reminding trials (Spreen and Strauss, 1998).

Peters, Levin and Kelly (1977) indicated that impaired divers performed significantly worse on delayed auditory memory, however the methodology in this study was questionable, and will be discussed in the following section. Andrews et al. (1986) also found that the divers performed significantly worse, but suggested that this may have been attributable to an artefact of multiple testing, and that the scores were not poor enough to suggest neurological impairment.

Tetzlaff et al. (1999) indicated that decreased immediate recall was significantly related to years of diving, and impaired immediate and delayed recall of auditory information was related to mean maximum depth. This significant result could either be attributed to the age of the divers, since this was an elderly group, or to the increased sensitivity of the memory test used. The SRT is widely used for assessing memory after head injury, and is considered to be a useful preclinical indicator of the development of dementia (Spreen and Strauss, 1998).

The other studies (Williamson, Clarke and Edmonds, 1987; Bast-Pettersen, 1999; Cordes et al., 2000) failed to distinguish between divers and non-divers on immediate or delayed auditory memory. Although Cordes et al. (2000) reported no significant overall differences in memory, the authors noted that the divers showed a significantly lower rate of recall on the first trial of the verbal paired associates (WMS), and a higher rate of forgotten pairs in the fourth trial.

2.5.2. Immediate and Delayed Visual Memory

Visual memory (immediate and delayed) has been assessed in a number of studies, using the visual reproduction subtest of the WMS (Peters, Levin and Kelly, 1977; Andrews et al., 1986), a tactual performance test (Bast-Pettersen, 1999), the Rey Complex Figure Test (Tetzlaff et al., 1999) and the Corsi Block Tapping Test (Cordes et al., 2000).

Bast-Pettersen reported a significant difference between divers and controls on the tactual performance test, but indicated that the scores were normal by clinical standards, and were also significantly related to education in a stepwise regression procedure. Tetzlaff et al (1999) also found that divers performed significantly worse on delayed recall of visual material.

Andrews et al. (1986) and Cordes et al. (2000) found no significant differences on this measure. Peters et al. (1977) did not distinguish between auditory and visual memory performance in their results.

2.5.3. Tracking

Tracking ability is considered to be highly sensitive to the effects of brain injury, particularly frontal lobe dysfunction (Lezak, 1995). Trail Making Test B has been used in several studies (Peters, Levin and Kelly, 1977; Fueredi, Czarnecki and Kindwall, 1991; Tetzlaff et al., 1999; Bast-Pettersen, 1999; Cordes et al., 2000) to assess this function.

Peters, Levin and Kelly (1977) found significant results on this measure, however the methodological flaws of this (1977) study will be discussed in the following section. Tetzlaff et al. (1999) also found significant results in their group of elderly divers. The remaining studies failed to find significant results.

2.5.4. Motor Speed

Motor speed was commonly assessed using the Symbol Digit Modalities Test (SDMT) (Andrews et al., 1986; Tetzlaff et al, 1999) and the Trail Making Test part A (TMTA) (Peters, Levin and Kelly, 1977; Fueredi, Czarnecki and Kindwall, 1991; Bast-Pettersen, 1999; Tetzlaff et al., 1999). Neither of these tests are pure measures of motor speed. The grooved pegboard test has also been used (Fueredi, Czarnecki and Kindwall, 1991; Bast-Pettersen, 1999). Williamson, Clarke and Edmonds (1987) used the Bourdon-Wiesma test of sustained attention and psychomotor speed, as well as the Digit Symbol test from the Wechsler Adult Intelligence Scale (WAIS) to assess this function. Cordes (2000) measured fine motor skills using the finger tapping test.

Peters, Levin and Kelly (1977) found that the divers were significantly slower in psychomotor speed. Tetzlaff et al. (1999) supported this result using the SDMT, but not the TMTA. However, the other studies (Andrews et al, 1986; Fueredi, Czarnecki and Kindwall; Bast-Pettersen, 1999; Cordes et al., 2000) found no significant differences between the groups on this measure. Andrews et al. (1986) found a significant correlation between dive stress and performance on the SDMT. Williamson, Clarke and Edmonds (1987) found a statistically significant result in the opposite direction, with the diver group outperforming the non-divers on psychomotor speed (Bourdon Wiesma test). However, the divers in this study performed worse than the control group in the Digit Symbol test. The results obtained are tabulated below.

Table 1: Comparison of instruments used to measure motor speed

Author	Instruments	Function	Result
Peters, Levin and Kelly (1977)	TMTA Finger tapping	Psychomotor speed	Divers slower Divers slower
Andrews et al. (1986)	SDMT	Cerebral dysfunction	No difference
Williamson, Clarke and Edmonds (1987)	Bourdon Wiesma Digit symbol	Attention and speed Psychomotor performance	Divers faster Divers slower
Fueredi, Czarnecki and Kindwall	TMTA Digit symbol		No difference No difference

(1991)	Grooved pegboard	Motor speed	No difference
Bast-Pettersen (1999)	TMTA Digit Symbol Grooved pegboard	Effectiveness Effectiveness Motor speed	No difference No difference No difference
Tetzlaff et al. (1999)	TMTA SDMT	Visual speed Visual scanning	No difference Divers slower
Cordes et al. (2000)	Finger tapping test	Fine motor skills	No difference

2.5.5. Insight and Judgement

Insight and judgement have infrequently been assessed, with most researchers preferring to assess general intelligence, using subtests of the WAIS (Peters, Levin and Kelly, 1977; Bast-Pettersen, 1999; Cordes et al., 2000). Tetzlaff et al (1999) used an equivalent of the National Adult Reading Test to assess premorbid functioning.

Results (Bast-Petterson, 1999; Tetzlaff et al., 1999; Cordes et al, 2000) suggested that there were no significant differences between the groups in intelligence. Peters, Levin and Kelly (1977) reported a significant difference, however this study was methodologically flawed in the selection of subjects into groups.

2.5.6. Word Initiation

Only two studies (Andrews et al., 1986 and Cordes et al., 2000) have investigated the effects of diving using the Controlled Oral Word Association Test as a measure of verbal fluency or word initiation. Neither study reported a significant result, however, Cordes et al. (2000) obtained a result approaching significance ($p = 0.08$) in the expected direction, and the divers in this study were navy divers who performed carefully controlled diving which is likely to be a protective factor against injury.

2.6. Criticisms of Previous Research

Studies undertaken in this area to date have been criticised due to the lack of inclusion of suitable control groups and lack of standardisation of diagnostic criteria (Campbell, 2002; Calder, 1992; Edmonds and Hayward, 1987, in McQueen, Kent and Murrison, 1994; Broome and Pitkin, 1997; Wilmshurst, 1997; Bast-Pettersen, 1999). Other concerns included a reliance on anecdotal evidence and investigations with mixed groups of divers, some of whom had suffered DCS and others who had not (Todnem, Nyland, Kambestad and Aarli, 1990; Todnem et al., 1991).

A study conducted by Peters, Levin and Kelly (1977) compared a group of divers with a history of DCI on neurological and psychological performance. They divided these divers into an impaired and a control group based on their performance on neuropsychological tests. The methodology in this study is questionable because of a systematic bias due to the selection of the two groups being based on performance on the neuropsychological tests.

Calder (1992) implicated the inadequacy of psychological tests, limitation of diagnostic categories and deficiency of statistical analyses. Another concern is that, while there have been several studies of the effects of deep diving, few studies have focused on the chronic sequelae of shallow water exposure (Williamson, Clarke and Edmonds, 1987). Shortcomings of the studies that have focussed on the chronic cognitive effects of shallow water diving in the absence of DCI will be discussed.

Andrews et al. (1986) and Williamson, Clarke and Edmonds (1987) compared abalone divers with non-diving controls. Andrews et al. (1986) expressed surprise that they had found no significant differences, despite the fact that the abalone divers reported irritability, slowness and confusion after diving, and that they found an association between an estimate of dive stress and neuropsychological performance. The authors attributed this to transient effects of diving. However, Williamson, Clarke and Edmonds (1987) pointed out that abalone diving probably attracts a high proportion of risk takers, and suggested that the performance of the divers on tests, particularly or reaction time or requiring motivation, may reflect a bias that could obscure any deterioration on neurobehavioural tests.

Bast-Pettersen (1999) compared a group of commercial divers with non-diving controls, and found no significant differences except in reaction time. The author's study can be criticised due to the large age difference between her groups, which necessitated the use of conversion to age-related scores, which may have obscured differences in the results. Bast-Pettersen (1999) used construction divers; a group that the author admitted is a "selected group" (p. 54) due to the health requirements that they must meet annually to continue to work. Therefore, it is likely that the author was assessing only the divers who were still relatively unimpaired, and cognitive deficits may have been found if the assessment had included construction divers who had stopped this work.

Cordes et al. (2000) compared a group of military divers with matched non-diving military controls. They found no significant differences except in divided attention. They suggested that impaired divided attention may be the first indicator of cortical dysfunction, but concluded that diving under controlled conditions is safe. They based this conclusion on the fact that all results on testing were subclinical. However, subclinical results could still be meaningful if they represent a decrease in functioning for the individual, particularly when it is possible that these individuals may continue to deteriorate as they age, as has been postulated by other authors (Calder, 1992; Tetzlaff et al., 1999).

Military divers are a highly select group due to their strict adherence to the decompression procedures. A study conducted by Hoiberg (1986, in Todnem, Nyland, Kambestad and Aarli, 1990), into the incidence of DCI in naval divers over a 12-year period, found that only 2.4% had suffered DCI. This suggests that controlled diving is likely to be comparatively safe.

2.7.Summary

This section has reviewed the physiology of diving, focussing on the gas laws and decompression illness. Relevant research on the different types of diving was discussed. The effects of diving in the absence of DCI were discussed, and the neuropsychological measures used to explore potential deficits were elaborated on. Finally, methodological flaws of previous research were reported.

2.8. Conclusion

Although the consequences of DCI have been extensively researched and appear to be well understood, the same cannot be said of the potential chronic cognitive effects of diving in the absence of DCI. Research discussed in this section has proved to be limited and methodologically flawed, and has also focussed on the neurological rather than the neuropsychological implications of diving.

Recent research into the chronic cognitive sequelae of shallow water diving has produced contradictory results, and has also been hampered by methodological concerns. Well-designed studies have indicated that subtle differences are apparent between divers and non-diving controls, although these differences are frequently not considered to be of clinical significance.

CHAPTER 3: METHODOLOGY.

3.1. Introduction

The aim of the study was to investigate the chronic cognitive effects of diving in the absence of DCI. The research focused on a comparison of neuropsychological test results in a group of rescue divers, a group of sport divers and a control group of non-divers, in order to investigate possible cognitive effects from repeated diving and decompression on divers without overt neurological insult. Neuropsychology "is the applied science concerned with the behavioural expression of brain dysfunction" (Bast-Petterson, 1999, p. 51). The sensitivity of the measurement techniques renders them valuable tools for investigating subtle behavioural alterations.

It was hypothesised that divers would score lower than the control subjects on neuropsychological measures of attention, concentration, mental tracking, perceptual-motor speed, insight and judgement, initiation and visual and auditory immediate and long-term memory. This supposition was based on the theory that cumulative subclinical episodes of decompression illness would resemble the effects of repeated mild traumatic brain injuries. Mood state was also assessed in order to assess potential differences between the groups, based on findings in previous research (Andrews et al., 1986).

A further hypothesis was that, of the group of divers, the sport divers would be more detrimentally affected on those measures than the rescue divers. This assumption was based on the strict adherence by rescue divers to the provisions of the U.S. Navy dive tables (1993) and the emphasis on physical fitness and lack of alcohol use prior to and after diving, which were likely to be protective factors against central nervous system injury. Alcohol use prior to or after a dive increases risk due to the dehydrating effect of alcohol (Kayle, 1994).

Holden, Morsman and Lane (1992) have suggested that in their experience, many sport divers do not use ideal decompression procedures, and may use diving computers, which are less stringent than the dive tables. Sport divers are also more likely to make repetitive dives, which could lead to injury if the decompression tables are not consulted regarding residual nitrogen loading (Kayle, 1994).

The design of the study was survey research intended to reveal potential differences in the three groups on the neuropsychological measures believed to be affected by chronic exposure to increased pressure and compression-decompression. Test selection was based on previous research as well as neuropsychological theory regarding the sequelae of mild traumatic brain injury (Lezak, 1995; Raskin and Mateer, 2000). Subjects were matched for age.

An attempt was made in the current study to avoid some of the methodological flaws in previous studies. The following factors were taken into account:

(1) Subjects who had a history of decompression illness, or who had suffered any form of head injury were excluded. This was a weakness of several previous studies, which used mixed groups of subjects.

(2) Many studies have not included a control group. In this study, a control group of non-diving firefighters was used.

(3) Subjects had completed their last dive at least one week prior to testing, to avoid the confounding variable of acute effects of diving.

(4) Subjects in the diver and control groups were matched for age, which has been a weakness of previous studies.

(5) Several studies have relied on anecdotal evidence. This study focussed on differences in performance on reliable tests.

(6) The majority of the research into the effects of diving has focussed on the effects of deep diving. This study is concerned with the effects of shallow water exposure.

3.2. Subjects

The study employed three groups of subjects, with a total number of 49 participants. The rescue divers and the control group of non-divers were selected from volunteers on duty at the Durban, Amanzimtoti and Richard's Bay Fire Departments. The sport divers were selected from volunteers who responded to an advertisement placed in a diving newsletter and on a diving website. The control group was selected to match the diving groups on the potentially confounding variables of age. An attempt was made to match the subjects for education level, but this proved to be impossible as the majority of sport divers who responded to the advertisement had tertiary education.

Participants from the sport and rescue diver groups had not dived in the past 7 days, in order to avoid the confounding variable of acute cognitive effects of diving.

3.2.1. Rescue Diver Group

This group was selected from an opportunity sample of Class IV rescue divers registered with the Department of Labour, who were on duty at the Durban, Amanzimtoti and Richard's Bay Fire and Emergency Services Departments. Class IV is a category of diver registration in the Diving Regulations, 1991. These divers are trained in accordance with a national curriculum, are restricted to the use of self-contained underwater breathing apparatus (Scuba), and are limited to a maximum dive depth of 50 metres. They are required by the regulations to comply with safety requirements, including the use of recognised dive tables during diving operations.

These divers were appropriate for this study as they are a relatively homogenous group in terms of occupation, training, experience, and physical fitness, and they regularly undertake dives to depths exceeding 30 metres as part of their training. Instances of DCI are rare in rescue divers. Volunteers were obtained from all 3 shifts of diving personnel employed by the fire departments.

The final sample included 17 males between 24 and 41 years of age, with a mean age of 31 years. The representative subject had been diving for 6.6 years. This sample had completed between 10 and 14 years of formal education, with a mean of 12.29 years.

3.2.2. Sport Diver Group

Selection was made on the basis of choosing the first 17 candidates who met the inclusion criteria. The sample ranged from 23 to 47 years of age, with a mean age of 35 years. They had completed between 12 and 17 years of formal education, with a mean of 14 years. They had been diving for an average of 7.1 years.

3.2.3. Non-diver Control Group

Seventeen non-diving volunteers between the ages of 22 and 41 (mean age 31) were recruited on a voluntary basis as an opportunity sample from the Durban Fire Department, selected from the three shifts. The control group had received between 10 and 12 years of formal education, with a mean of 11.94 years.

A battery of group - and individually - administered tests, as well as a demographic questionnaire and a mood state questionnaire, were completed by the volunteers under the same conditions over a period of several weeks.

Data was discarded from:

- Subjects who did not complete all the required tests (1 case)
- Subjects whose lack of proficiency in English may have prejudiced the results (2 cases)

3.3. Materials and Measures

3.3.1. Biographical Questionnaire

All subjects in the rescue diver, sport diver and non-diver control group were asked to complete a confidential questionnaire (Appendix 1). This was aimed at ensuring that the three groups were as homogeneous as possible with regard to age, and establishing that the divers from both groups had completed a similar number of dives. Another function of the questionnaire was to obtain a fairly detailed diving history. Details in the questionnaire included:

(1) Age, gender, occupation, and level of education

(2) Medical history. Participants were asked whether they had a history of head injury, concussion, loss of consciousness or decompression sickness

(3) Diving history, including number of years of diving, number of dives, deepest dive, and average dive depth.

(4) Drinking and smoking habits

(5) Height and weight. This was collected in order to compute a body mass index (BMI) for each participant.

(6) Alcohol consumption prior to and following diving

(7) Date of last dive. This was obtained to ensure that the project was measuring chronic rather than acute effects of diving.

(8) Mode of decompression procedure followed (tables, computer or no tables).

3.3.2. Profile of Mood States Questionnaire

All subjects were asked to complete a 65-item questionnaire on mood state (McNair, Lorr and Droppleman, 1992; Appendix 2). The subject is required to respond on a 5-point Likert-type scale to adjectives describing their mood over the past week, varying in response from 0 (not at all) to 4 (extremely). The questionnaire was designed to measure fluctuating affective states (McNair, Lorr and Droppleman, 1992).

The profile of mood states (POMS) questionnaire has identified 6 factors: tension-anxiety, depression-dejection, anger-hostility, vigour-activity, fatigue-inertia and confusion-bewilderment. Raw scores were converted to T-scores using norms for a college population. The questionnaire was used to control for the possible effects of depression and anxiety on test performance, and to reveal potential differences between the three groups in mood state.

Lezak (1995) indicated that the POMS has been successfully used to examine the effects of environmental toxins on workers, as well as head trauma.

3.3.3. Group-Administered Neuropsychological Test Battery

The group-administered test battery included tests of immediate and delayed auditory memory, incidental and delayed visual memory, perceptual-motor speed and tracking, insight and judgement and word initiation. Tests were selected on the basis of findings in previous studies on divers (Peters, Levin and Kelly, 1977; Andrews et al., 1986; Williamson, Clarke and Edmonds, 1987; Feuredi, Czarnecki, and Kindwall, 1991; Bast-Petterson, 1999; Tetzlaff et al, 1999; Cordes et al., 2000), and from general theory of neuropsychology (Lezak, 1995). Most of the tests are traditionally administered individually. The tests were administered in a standard order with standardised instructions as suggested by the various test manuals. Testing took approximately one hour.

The selected tests, in the order presented, were as follows:

3.3.3.1.Logical Memory, Immediate Recall (LMI)

This test forms part of the Wechsler Memory Scale – Revised (WMS-R). It is a form of story recall, which provides a measure of the amount of information retained when more information is provided than the average person is able to recall in one presentation, and the contribution of meaning to retention and recall (Lezak, 1995). It is believed to assess left temporal lobe function (Andrews et al., 1986). Lezak (1995) suggests that story memory tasks are analogous to supraspan recall due to the inclusion of more data than can be remembered.

Logical memory consists of the presentation, followed immediately by free recall, of two short stories. Story A contains 24 memory units, and story B 22. The subjects receive credit for each idea recalled. This test was administered in a written form to allow for group presentation. Scores were based on the guidelines in the WMS-R manual, but were not converted into percentiles for data analysis due to the potential unreliability of the norms for a South African population, particularly considering the unfamiliar nature of the stories.

3.3.3.2. *Complex Figure Test, Copy Administration (CFT-C)*

A. Rey devised the complex figure as a measure of perceptual organisation and visual memory (Lezak, 1995). The test consists of a reproduction of the complex figure, using coloured pens in order to ascertain the order in which the copy was attempted, as a measure of planning. The drawing was scored using the Rey-Osterreith scoring system (Lezak, 1995), with a maximum score of 36. Scores were not converted into percentiles due to the lack of norms for a South African population.

3.3.3.3.*Symbol-Digit Modalities Test, Written Administration* (SDMT)

This test was designed to be sensitive to cerebral dysfunction of diverse aetiologies (Smith, 1982). The written administration involves the conversion of meaningless geometric designs into written number responses. This is a timed test, and the subjects are given 90 seconds to complete as much of the form as possible. It is a considered a useful measure of the cerebral and peripheral sensorimotor mechanisms, and is relatively culture-free. Scoring was based on the number of correct substitutions made within the 90-second time limit.

3.3.3.4.*Complex Figure Test, Incidental Recall (CFT-IR)*

This involved an uncued recall of the complex figure diagram that had previously been copied. It is a measure of incidental recall of complex visuo-spatial information, as well as an indication of visuo-spatial problems (Lezak, 1995). The copy was scored using the Rey-Osterreith scoring system (Lezak, 1995), with a maximum score of 36.

3.3.3.5.*Similarities*

This is a subtest of the South African Wechsler Adult Intelligence Scale – Revised (SAWAIS-R). It provides a measure of verbal concept formation, and is an excellent test of general mental ability (Lezak, 1995, Bast-Pettersen, 1999). According to Lezak (1995), a depressed Similarities score may be associated with left temporal and frontal lobe involvement. The test is comprised of ten pairs of items, and the subject is required to indicate the similarity between the item pairs. This test was administered in a written format. Scoring was based on the guidelines in the SAWAIS-R scoring manual, and scores were standardised for age.

3.3.3.6. *Comprehension*

This test forms part of the SAWAIS-R battery. It involves questions assessing common sense judgement and practical reasoning (Lezak, 1995). This test was administered in a written format. Scoring was based on the guidelines in the SAWAIS-R scoring manual, and scores were standardised for age.

3.3.3.7. *Logical Memory (WMS-R), Delayed Recall*

This test is a measure of delayed recall of auditory information. The participants were requested to write down all that they were able to recall of the two short stories that had been presented to them at an earlier stage in the testing procedure. Scoring was based on the guidelines in the WMS-R manual, but raw scores were not converted into percentiles due to the lack of norms for a South African population.

3.3.3.8. *Complex Figure Test, Delayed Recall (CFT-D)*

This involved the redrawing from memory of the complex figure, after approximately a one-hour delay. This provided a measure of delayed visual recall. The recall drawing was scored using the Rey-Osterrieth method (Lezak, 1995), with a maximum score of 36.

3.3.4. Individually-Administered Neuropsychological Test Battery

The individually administered test battery consisted of tests that precluded group administration because they were timed, or required one-on-one interaction between examiner and subject. They included tests of immediate and delayed auditory memory, word initiation, perceptual-motor speed, and mental tracking. All tests were administered in a standard order with standardised instructions recommended by the relevant testing manuals. Testing took approximately 20 minutes.

The tests, in the order presented, were as follows:

3.3.4.1. *Auditory-Verbal Learning Test (AVLT): List A Trials I – V, List B, Trial VI*

This test, which was developed by Rey, was designed to measure immediate memory span, demonstrate a learning curve, and elicit proactive and retroactive interference (Lezak, 1995). It consists of 5 presentations with recall of a list of 15 words; one presentation and recall of a second 15-word list, and a sixth recall trial of the original list

(List A), without another presentation of the list. Administration takes approximately 20 minutes. Trial I is a measure immediate word span recall, while Trials I to V demonstrate a learning curve (rate of learning). List B produces an additional measure of immediate word span and also reveals difficulty in switching between the two lists. Trial VI measures delayed recall and is also a measure of shifting ability. The number of repetitions was also recorded in order to provide a measure of mental tracking. Scoring consisted of a raw score for Trials I, V, List B and VI, a total word score and the number of repetitions. Scores were not converted into z-scores due to concern about the reliability of the norms available.

3.3.4.2.Trail *Making Test A and B (TMTA, TMTB)*

This test is considered to be a reliable indicator of visual conceptual and visuomotor tracking and shifting (Lezak, 1995). Part A requires the subject to draw lines to consecutively numbered circles on a worksheet, and Part B involves alternating between consecutive numbers and letters (1 – A – 2 – B – 3 – C etc.). This is a timed test, and the subject is required to complete it accurately as fast as possible, without lifting pencil from paper. This test is considered to be extremely sensitive to the effects of brain injury, particularly frontal lobe injury (Lezak, 1995). Part A is primarily an indicator of motor speed, while part B assesses speed as well as mental tracking and shifting. Scoring involved recording the time taken to complete each part.

3.3.4.3. *Controlled Oral Word Association Test (COWA)*

This test was designed to measure word initiation and verbal fluency (Andrews et al., 1986), and is considered to be a sensitive indicator of frontal lobe dysfunction (Lezak, 1995). The subject is asked to provide as many words, starting with a given letter, as possible in one minute. The letters used were C, F and L, and the subject was instructed not to use any proper nouns or derivatives of the same word. Any repetitions and contraventions of the instructions were recorded to provide a measure of mental tracking. Scoring consisted of the addition of the number of correct words for each letter, and results were adjusted for education (Lezak, 1995).

3.3.4.4. *Digit Span (DSp) Forwards and Backwards (WMS-R)*

This test is a measure of immediate verbal memory span (Lezak, 1995). It consists of the examiner reading a list of digits to the subject at the rate of one per second. In the Digit span forward task, the subject is required to immediately repeat the list in the sequence given. Following a correct response, the examiner reads a longer number sequence. This test measures attention. Digit span backwards consists of a series of digits that the subject must repeat in the reverse order. The length of the series continues to increase until 2 consecutive trial of the same number of digits has been failed. This test is a good measure of mental tracking (Lezak, 1995). Number of errors was also recorded in order to provide a measure of attention. Scoring was accomplished using the guidelines in the WMS-R manual, and consisted of separate scores for digits forward, digits backward and total digits, as well as for total number of errors.

3.3.4.5. *AVLT, Delayed Recall and Recognition*

This consisted of the recall of List A, which had been presented approximately 1 hour previously. This is an assessment of delayed auditory memory. Following the recall trial, the participants were read a list of 50 words, which contained the words from List A and List B, as well as distractor words, and were asked to select only the words from List A. The recognition trial assesses recognition memory, and may also elicit retroactive interference. It may also be used as an indicator of mental tracking, as the participant is aware that the list contained only 15 words, and should not endorse many more than this. Scoring for the recall trial consisted of the number of words recalled. Scoring for recognition was a calculation of the total number of true positives minus the number of false positives, to provide an adjusted recognition score.

3.4. Procedure

Following recruitment, a meeting was held in which the aim and method of the study was explained to all volunteers and informed consent obtained (Appendix 3). Confidential biographical (Appendix 1) and Profile of Mood State questionnaires (Appendix 2) were completed. Data collection continued over a period of several weeks according to the shifts of the rescue diver and control group.

The administration of the group tests took place first, followed by the individual testing. Following the testing, subjects were debriefed, and asked about their experience of the testing. They were informed that they would be given access to the report once it was complete, and that a presentation would be made to them explaining the results. They were informed that they could request an explanation of their individual results if they so desired.

CHAPTER 4: RESULTS

4.1. Data Analysis

Study results were analysed using SPSS/PC+ (Noresis/SPSS Inc., 1989-1997), and the significance level set at 0.05. One-way Analysis of Variance (ANOVA) was performed to analyse group differences. When all three groups were included in the analysis, Tukey's Honestly Significant Difference (HSD) post hoc tests were used to determine where the groups differed.

Multiple stepwise linear regression analysis was used to control for potential confounding variables. The potential confounding variables included as independent variables were age, education and diving experience.

Since the data output on SPSS is voluminous, the statistical data has not been included in the appendix. All data is available on disk.

4.2. Demographic Data from the Biographical Questionnaire

Analysis of the demographic questionnaire, using one-way ANOVA, showed that the rescue diver, sport diver and control group did not differ significantly with respect to age. The rescue diver and control group did not differ in educational level, however the sport divers had a significantly higher level of education than the other two groups (F = 10.933; df = 2; p = < 0.001).

Significant differences were found between the three groups with respect to alcohol use (F = 12.689; df = 2; p = < 0.001). There were no significant differences in smoking or exercise habits between the three groups. Demographic details are tabulated below.

Table 2: Demographic profile of subjects (n = 49)

Variable	Rescue Diver Grp Mean (S.D.)	Sport Diver Group Mean (S.D.)	Control Group Mean (S.D.)
Mean age (yrs)	30.82 (5.3)	34.87 (8.2)	30.53 (4.9)
Age range (yrs)	24 – 41	23 – 47	22 – 41
Mean education	12.29 (1.2)	14.07 (1.8)	11.94 (0.97)
Alcohol (units/wk)	3.4 (3.6)	7.0 (5.96)	0.0 (0)
Exercise (days/wk)	3.7 (1.4)	4.2 (2.01)	3.9 (1.3)

Independent samples T-tests were performed between the two diving groups. There were no significant differences in number of years of diving, diving frequency or usual dive depth. However, the rescue divers had dived to a significantly deeper level on their maximum dive (t = 2.747; df = 30; p = 0.01).

Regarding the use of tables when diving, 100% of rescue divers indicated that they adhered to the dive tables. Of the sport divers, 8 reported using tables, and 6 used diving computers. One diver admitted that he does not follow either the dive tables or a dive computer. Data on diving history is reported on the following page.

Table 3: Data on diving history

Variables	Rescue Diver Group Mean (S.D.)	Sport Diver Group Mean (S.D.)
Diving Years	6.6 (4.1)	7.1 (3.4)
Number of Dives	80.4 (58.2)	176.9 (240.3)
Diving Freq. (per month)	1.5 (0.6)	2.3 (2.1)
Maximum depth (m)	46.6 (7.7)	38.1 (9.8)
Usual depth (m)	24 (5.9)	23.8 (5.8)

An independent samples T-test was performed between the two diving groups to establish whether there was any difference in Body Mass Index (BMI). The result was non-significant ($t = 0.557$; $df = 28$; $p = 0,58$). The rescue divers had a mean BMI of 25.76, and the sport divers a mean BMI of 25. Results are tabulated below.

Table 4: Independent samples T-test on BMI

Variable	T	df	p
BMI	0.557	28	0.58

4.3. Profile of Mood States Questionnaire

The POMS questionnaire was analysed using a multiple one-way ANOVA. There were significant differences between the three groups on POMS fatigue and POMS confusion. Results are tabulated below.

Table 5: ANOVA of POMS questionnaire

Variable	F	df	p
POMS Fatigue	7.808*	2	0.001
POMS Confusion	4.650*	2	0.014

*** Indicates a significant result (α = 0.05)**

Tukey's HSD post hoc tests were conducted to reveal where the differences between the three groups lay. Results indicated that the sport and rescue diver groups both demonstrated significantly higher fatigue scores than the control group. The rescue divers also had a significantly higher confusion score than the control group. Results are presented on the following page. Significant results are presented graphically thereafter.

Table 6: POMS scores (Tukey's HSD) between groups

Mood State	Group 1	Group 2	Mean Diff. (1 – 2)	Significance p
Anxiety/Tension	Rescue	Sport	5.2706	.188
		Control	5.5294	.143
	Sport	Control	.2588	.996
Depression	Rescue	Sport	4.8745	.261
		Control	3.5294	.467
	Sport	Control	-1.3451	.900
Anger	Rescue	Sport	3.1412	.727
		Control	4.0588	.569
	Sport	Control	.9176	.973
Vigour	Rescue	Sport	-8.6275	.999
		Control	-2.1765	.702
	Sport	Control	-2.0902	.736
Fatigue	Rescue	Sport	-.8627	.935
		Control	7.8235*	.006
	Sport	Control	8.6863*	.003
Confusion	Rescue	Sport	4.2941	.191
		Control	7.1176*	.011
	Sport	Control	2.8235	.481

*** Indicates a significant result ($\alpha = 0.05$)**

Figure 3: Group comparisons on POMS fatigue

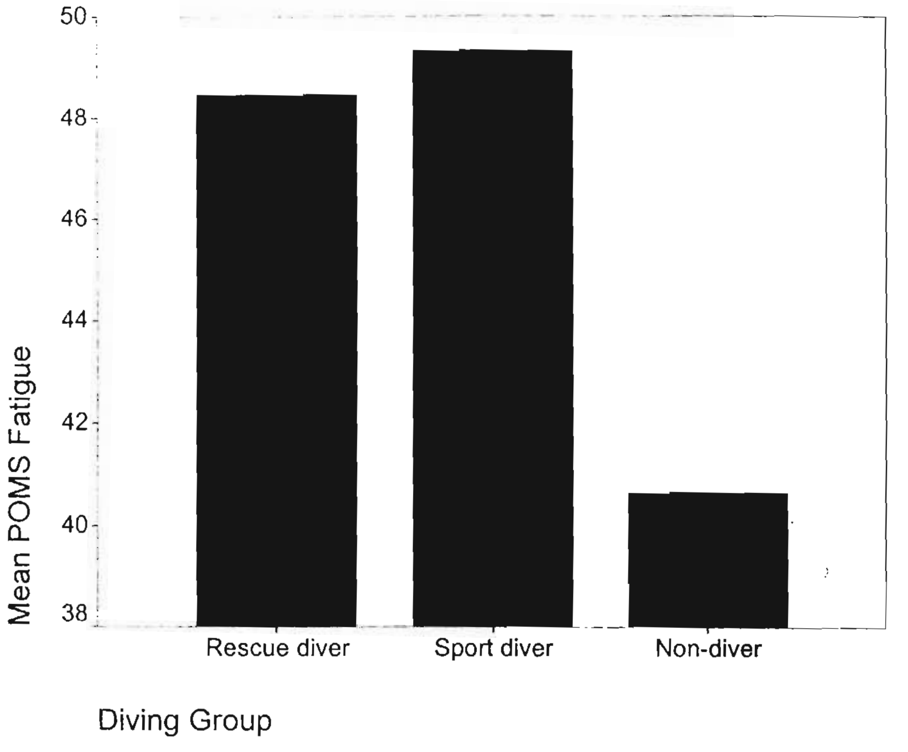
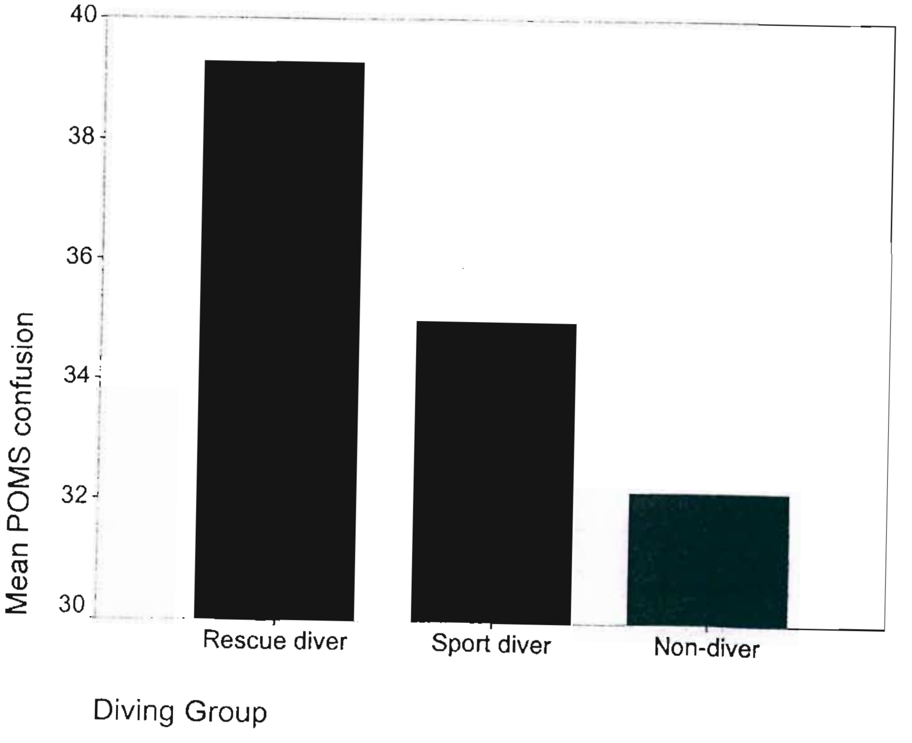


Figure 4: Group comparisons on POMS confusion



A multiple stepwise regression analysis was performed on the POMS Fatigue score to exclude potential confounding variables. The independent variables entered into the regression were diving group, age, and education. Diving group was found to be the best single predictor of POMS Fatigue ($R^2 = 0.174$; $F = 9.905$; $df = 1$; $p = 0.003$). Diving group and age were the best multiple predictors ($R^2 = 0.275$; $F = 8.733$; $df = 2$; $p = 0.001$) of fatigue.

Table 7: Multiple stepwise regression of POMS Fatigue score

Variable	Model	R^2	F	df	p
POMS Fatigue	1. Diving Group	0.174	9.905*	1	0.003
POMS Fatigue	2. Diving group + Age	0.275	8.773*	2	0.001

*** Indicates a significant result ($\alpha = 0.05$)**

4.4. Neuropsychological Test Results

All results were analysed using a multiple one-way ANOVA, with Tukey's HSD post hoc test used to establish where the significant differences between the three groups lay. Regression analyses were used to control for the confounding independent variable of education. Results of individual tests are grouped according to the type of neuropsychological functioning that the tests measure.

4.4.1. Immediate Auditory Memory

Analysis of immediate auditory memory measures using one-way ANOVA indicated that there was a significant difference between the three groups in performance on Logical Memory I (F = 13.244; df = 2; p = < 0.001). Results are presented below.

Table 8: One-way ANOVA of LM-I

Test	F	df	P
LM - I	13.244*	2	< 0.001

*** Indicates a significant result ($\alpha = 0.05$)**

Post Hoc analysis using Tukey's HSD test revealed that the sport divers performed significantly better than both the rescue divers and the control group on Logical Memory I (WMS-R). There were no significant differences in performance on the RAVLT (Immediate recall, List B or Total words), or the WMS-R Digit Span Forward measures. Results are tabulated below.

Table 9: Mean differences (Tukey's HSD) on immediate auditory memory

Test	Group 1	Group 2	Mean Diff (1 – 2)	Significance p
Wechsler Logical Memory Immediate	Rescue	Sport	- 5.7238*	.004
		Control	2.3304	.335
	Sport	Control	8.0542*	.000

RAVLT Immediate	Rescue	Sport	.6333	.593
		Control	1.1250	.193
	Sport	Control	.4917	.713
RAVLT List B	Rescue	Sport	1.3095	.174
		Control	1.1429	.250
	Sport	Control	-.1667	.969
Wechsler Digit Span – Forwards	Rescue	Sport	-.8429	.05
		Control	-.3929	.489
	Sport	Control	.4500	.381
RAVLT Total Words	Rescue	Sport	4.6238	.201
		Control	3.8571	.312
	Sport	Control	-.7667	.952

*** Indicates a significant result ($\alpha = 0.05$)**

A multiple stepwise regression analysis was performed to control for the potentially confounding variable of education. Performance on Logical Memory was significantly positively associated with years of education ($R^2 = 0.133$; $F = 7.222$; $df = 1$; $p = 0.01$). Age and diving group were excluded as potential predictor variables.

Table 10: Multiple stepwise regression of LM-I

Variable	Model	R^2	F	df	p
Logical Memory (I)	1. Education	0.133	7.222*	1	0.01

*** Indicates a significant result ($\alpha = 0.05$)**

4.4.2.Delayed Auditory Memory

A significant difference was obtained between the three groups on Logical Memory II (delayed recall), using one-way ANOVA. Results are presented below.

Table 11: One-way ANOVA of LM-II

Test	F	df	p
LM-II	6.707*	2	0.003

*** Indicates a significant result ($\alpha = 0.05$)**

Tukey's HSD test showed that the sport diver group performed significantly better than the other two groups on Logical Memory II (Delayed Memory). There were no significant differences on the RAVLT recall or recognition tasks. Results are presented below.

Table 12: Mean differences (Tukey's HSD) on delayed auditory memory

Test	Group 1	Group 2	Mean Diff (1 - 2)	Significance p
Wechsler Logical Memory Delayed	Rescue	Sport	-5.4286*	.019
		Control	.9464	.872
	Sport	Control	6.3750*	.004
RAVLT Recall	Rescue	Sport	-.4571	.886
		Control	.3929	.912
	Sport	Control	.8500	.642

RAVLT Recognition	Rescue	Sport	.9048	.773
		Control	.5714	.899
	Sport	Control	-.3333	.963

*** Indicates a significant result (α = 0.05)**

Biserial correlations were performed to compare performance on Logical Memory (Immediate) and Logical Memory (Delayed), and the two were highly significantly correlated (Pearson's correlation coefficient: r = 0.895; p = 0.01).

Table 13: Biserial correlation (Logical Memory I and II)

Tests	R	p
Logical Memory (I&II)	0.895*	0.01

*** Indicates a significant result (α = 0.05)**

4.4.3. Immediate Visual Memory

One-way ANOVA on the Rey CFT (Incidental recall) showed a significant difference between the three groups (F = 4.423; df = 2; p = 0.018). Results are tabulated below.

Table 14: One-way ANOVA of CFT-I

Test	F	df	P
CFT-I	4.423*	2	0.018

*** Indicates a significant result (α = 0.05)**

Tukey's HSD test showed that the sport diver group once again significantly outperformed the non-diver control group on the Rey Complex Figure Test (Incidental recall) however no significant differences were found between the other groups. Results are presented in Table 15, below.

Table 15: Mean differences (Tukey's HSD) on immediate visual memory

Test	Group 1	Group 2	Mean Diff (1 - 2)	Significance
Rey Complex Figure Test – Incidental Recall	Rescue	Sport	-3.2310	.191
		Control	1.9732	.519
	Sport	Control	5.2042*	.014

*** Indicates a significant result (α = 0.05)**

4.4.4. Delayed Visual Memory

No significant differences between the groups were found on the delayed recall trial of the CFT (F = 3.175; df = 2; p = 0.052). However, Tukey's HSD test indicated that the difference in scores between the sport diver and non-diver control group was approaching significance (p = 0.051). Results are tabulated below.

Table 16: Mean differences (Tukey's HSD) on delayed visual memory

Test	Group 1	Group 2	Mean Diff (1 - 2)	Significance
Rey Complex Figure Test –	Rescue	Sport	-3.5000	.176
		Control	1.0000	.858

Delayed Recall	Sport	Control	4.5000	.051**

**** Indicates a result approaching significance ($\alpha = 0.05$)**

Related samples T-test was conducted on the CFT (Incidental) and the CFT (Delayed), and the two tests were found to be highly significantly related (Pearson's correlation coefficient: $r = 0.863$; $p = < 0.001$). The T-test found that scores on the incidental and the delayed tests were not significantly different ($t = 0.239$; $df = 44$; $p = 0.812$). The results are tabulated below.

Table 17: Related samples T-test on CFT-I and CFT-D

Tests	t	df	p
CFT-I & CFT-D	0.239	44	0.812

4.4.5. Tracking

No significant differences were found between the groups in mental tracking ability, which was assessed using the WMS Digits backwards, TMTB, and RAVLT repetitions. Results are presented on the following page.

Table 18: Mean differences (Tukey's HSD) on tracking

Test	Group 1	Group 2	Mean Diff (1 - 2)	Significance
Wechsler Digit Span Backwards	Rescue	Sport	-.1286	.949
		Control	.7589	.166
	Sport	Control	.8875	.082
RAVLT Repetitions	Rescue	Sport	.8857	.804
		Control	-.4081	.954
	Sport	Control	-1.2875	.612
Trail Making Test B	Rescue	Sport	1.2233	.921
		Control	-2.2719	.748
	Sport	Control	-3.4952	.494

*** Indicates a significant result (α = 0.05)**

4.4.6. Motor Speed

There was a significant difference between the three groups on the SDMT ($F = 5.114$; df = 2; $p = 0.01$), however no differences were observed on the TMTA. The results of the one-way ANOVA are presented below.

Table 19: One-way ANOVA of SDMT

Test	F	Df	P
SDMT	5.114*	2	0.01

*** Indicates a significant result (α = 0.05)**

Differences between groups were explored further using Tukey's HSD post hoc test. Both the rescue divers and the sport divers significantly outperformed the control group on the SDMT (p = 0.032 and 0.018 respectively). Results are tabulated below.

Table 20: Mean differences (Tukey's HSD) on motor speed

Test	Group 1	Group 2	Mean Diff (1 - 2)	Significance
Symbol Digit Modalities Test	Rescue	Sport	-.5714	.981
		Control	7.8036*	.032
	Sport	Control	8.3750*	.018
Trail Making Test A	Rescue	Sport	2.5990	.407
		Control	1.7907	.640
	Sport	Control	-.8083	.909

*** Indicates a significant result ($\alpha = 0.05$)**

4.4.7. Insight and Judgement

Significant differences were obtained on both Similarities (F = 9.423; df = 2; p < 0.001) and Comprehension (F = 4.380; df = 2; p = 0.019) tests using ANOVA. Results are tabulated on the following page.

Table 21: One-way ANOVA on Similarities and Comprehension

Test	F	Df	P
Similarities	9.423*	2	< 0.001
Comprehension	4.380*	2	0.019

*** Indicates a significant result (α = 0.05)**

Post hoc analysis using Tukey's HSD test indicated that the sport divers performed significantly better than the non-diver control group on Similarities (SAWAIS-R). However, on the Comprehension test (SAWAIS-R), the sport divers performed significantly worse than the rescue divers (F = 4.380; df = 2; p = 0.016). Results are presented below.

Table 22: Mean differences (Tukey's HSD) on Comprehension and Similarities

Test	Group 1	Group 2	Mean Diff. (1 - 2)	Significance
SAWAIS-R Comprehension	Rescue	Sport	1.1119*	0.016
		Control	.7723	0.115
	Sport	Control	-.3396	0.634
SAWAIS-R Similarities	Rescue	Sport	-1.5738	0.063
		Control	1.2679	0.151
	Sport	Control	2.8417*	0.000

*** Indicates a significant result (α = 0.05)**

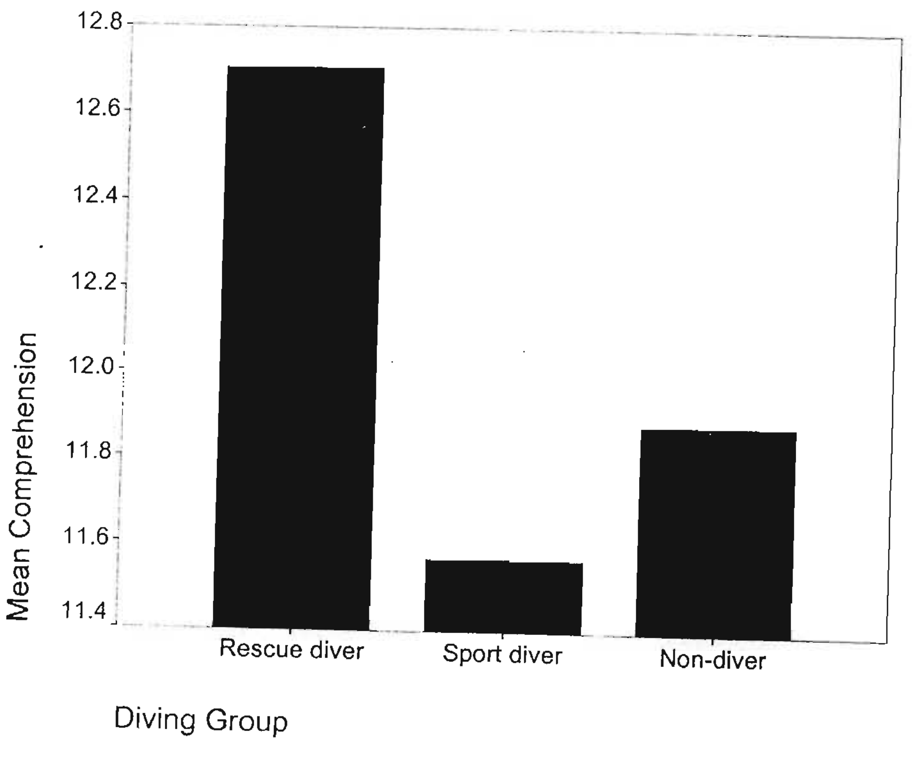
A multiple stepwise regression analysis was performed on the results of the Similarities test in order to control for the potentially confounding independent variable of education.

Education was found to be the most significant predictor of test performance ($R^2 = 0.197$; $F = 11.538$; $df = 1$; $p = 0.001$). Age, number of dives and diving group were excluded as predictor variables. Results are presented below.

Table 23: Multiple stepwise regression of Similarities

Variable	Model	R^2	F	df	p
Similarities	1. Education	0.197	11.538*	1	0.001

Figure 5: Group comparisons on Comprehension performance



4.4.8. Word Initiation

There were significant differences between the three groups in performance on the COWA (F = 5.730; df = 2; p = 0.006). Results of the ANOVA are presented below.

Table 24: One-way ANOVA of COWA

Test	F	Df	P
COWA	5.730*	2	0.006

*** Indicates a significant result (α = 0.05)**

Analysis of the post hoc test results (Tukey's HSD) revealed that the control group performed significantly better than the sport diver group (F = 5.730; df = 2; p = 0.006) on the COWA. The rescue divers also performed better than the sport divers at a level approaching significance (p = 0.052). Results are tabulated below, and a graphical representation is depicted thereafter.

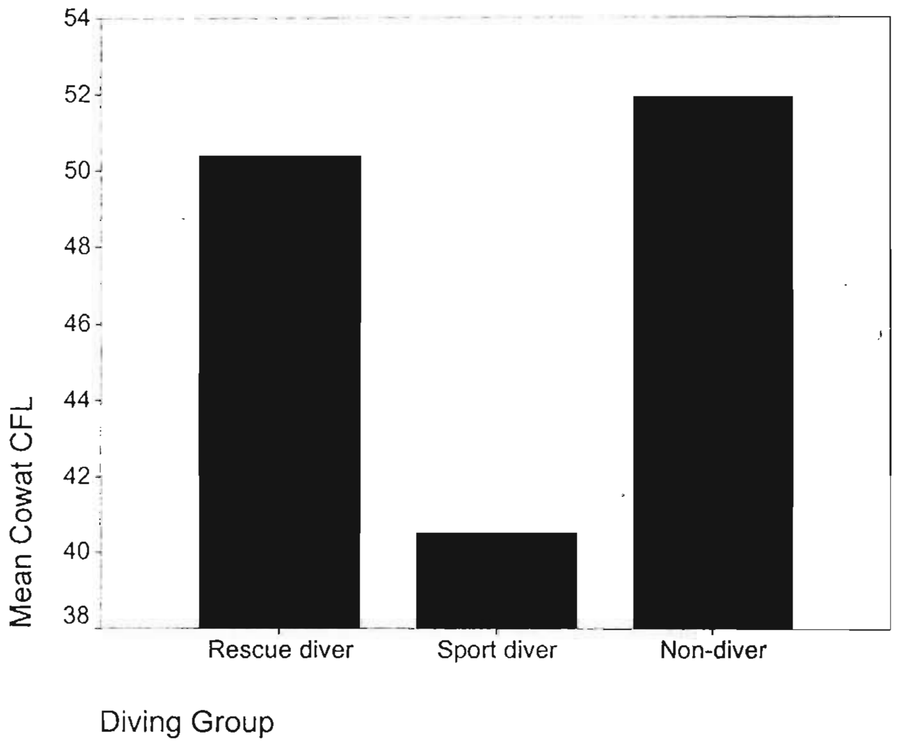
Table 25: Mean differences (Tukey's HSD) on word initiation

Test	Group 1	Group 2	Mean Diff (1 – 2)	Significance
COWAT C, F and L	Rescue	Sport	9.3238**	.052
		Control	-2.8929	.730
	Sport	Control	-12.2167*	.006

*** Indicates a significant result (α = 0.05)**

**** Indicates a result approaching significance (α = 0.05)**

Figure 6: Group comparisons on COWA performance



CHAPTER 5: DISCUSSION AND CONCLUSION

5.1. Demographic Data from the Biographical Questionnaire

The information obtained from the demographic questionnaire was used for screening in the initial phase of subject selection. It was also used to assess smoking, alcohol use and exercise habits, and to provide information on the diving history of the two diving groups. Results from the statistical analysis confirmed that there were no significant differences between the three groups in age, smoking or exercise habits.

The rescue divers were found to consume significantly more alcohol than the control group, and the sport divers admitted to consuming significantly more alcohol than both groups. This result is possible, but is somewhat questionable. The sport divers were likely to be more honest about their alcohol use since they were not assessed in a work environment (as the other two groups were), and would not have been apprehensive about the consequences of this disclosure.

Although an attempt was made to match participants for level of education, there was a significant difference in number of years of education between the sport divers and the other two groups. Unfortunately, this had an influence on the results on several of the tests, and future studies should attempt to control for this potentially confounding variable more vigorously.

The two diving groups proved to be homogenous for all but one of the indicators of diving experience. They were equivalent regarding number of years of diving, number of dives completed and usual dive depth. However, the sport divers showed a much greater range in number of dives completed (784 as opposed to 225 for the rescue divers). The rescue divers had dived to a deeper maximum depth, which is to be expected due to their training, which permits them to dive to a depth of 50 metres, whereas most sport divers are only permitted to dive to depths of 30 metres. The Body Mass Index of the two diving groups was not significantly different, and both groups fell into the normal range for BMI. This precluded the possibility that the sport divers may have been at a higher risk for cognitive damage due to excess body fat leading to increased nitrogen absorption.

The participants in this study tended to be younger than in previous studies (Andrews et al., 1986; Williamson, Clarke and Edmonds, 1987; Fueredi, Czarnecki and Kindwall, 1991; Bast-Pettersen, 1999; Tetzlaff et al., 1999; Cordes et al., 2000). This could have had an influence on the results, particularly due to the hypothesis of subclinical damage that is progressive (Calder, 1992; Wilmshurst, 1997). Todnem, Nyland, Kambestad and Aarli (1990, p. 712) have suggested, "at this age, the results from natural ageing in the nervous system are minor".

The divers in the current study had also completed fewer dives than in other studies (Andrews et al., 1986; Williamson, Clarke and Edmonds, 1987; Fueredi, Czarnecki and Kindwall, 1991; Bast-Pettersen, 1999; Tetzlaff et al., 1999; Cordes et al., 2000), since previous studies focussed on commercial divers who dived almost every day. This could also have contributed to the findings; due to the assumption that damage due to diving is cumulative (Calder, 1992; Wilmshurst, 1997).

Participants in the current study, particularly the sport divers, had a higher level of education than subjects in previous studies (Williamson, Clarke and Edmonds, 1987; Bast-Pettersen, 1999; Tetzlaff et al., 1999; Cordes et al., 2000). This could potentially have an impact on the results, particularly if Calder's (1992) contention of the "iceberg phenomenon of hidden damage" (p. 213) is taken into account. Calder (1992) has argued that erosion into the reserves of the brain may occur in the presence of silent bubbles, and that this subclinical damage may only become evident as divers age. In the case of the sport divers in this study, their higher level of education may be a protective factor against exhibiting signs of damage, since their 'reserves' are presumably greater, and they would therefore take longer to exhibit signs of damage.

5.2. Profile of Mood States Questionnaire

The scores obtained by the participants in the POMS questionnaire support, but are not entirely consistent with the mood state differences reported in previous research (Andrews et al., 1986; Calder, 1992; Reul et al., 1995). These studies reported significant differences between divers and non-divers in measures of anxiety, depression and fatigue. Peters, Levin and Kelly (1977) reported that impaired divers had MMPI profiles indicating acute distress, depression, anxiety, somatic concern, and disruption of cognitive efficiency.

In the current study the diving group was not found to be significantly different from the control group on the dimensions of anxiety or depression. This was in accordance with the finding of Cordes et al. (2000) of a non-significant result on both the Beck Depression Inventory and a self-rating mood scale. However, both diving groups in the current study differed significantly from the control group on fatigue, and the rescue divers differed from the control group on confusion. The rescue diving group reported higher levels of both fatigue and confusion than the control group, which was consistent with the findings of Reul et al. (1995), Calder (1992) and Andrews et al. (1986). Bast-Pettersen (1999) found no significant differences in neuropsychiatric symptoms (including questions regarding memory, concentration and fatigue) in her research.

The Fatigue score was entered into a multiple regression to control for the potentially confounding independent variables of age, education and number of dives. Diving group was found to be the most likely predictor of the outcome, suggesting that diving results in fatigue.

The potential aetiology of the fatigue and confusion amongst the experimental group was not pursued any further in this study. While the between group differences on fatigue and confusion were significant, the effect size as reflected by Eta Squared for fatigue was $\eta^2=0.253$ and for confusion was $\eta^2=0.168$. This means that 25% of the difference in fatigue and 17% of the difference in confusion can be attributed to group membership. Since η^2 is an upwardly biased estimate of effect size (Howell, 2002) this is not a large effect size.

The performance of the diving group in the various tests as discussed in more detail below was also not suggestive of any impairment due to fatigue. Thus although the between groups difference on these measures may have been statistically significant it appears to have been of less practical significance, and should be investigated further before conclusions are reached.

Lezak (1995) has criticised the POMS due to its limited norms, with no data available for normal adults at different educational levels. This is an important shortcoming since the rescue diver and control groups did not have tertiary education.

5.3. Neuropsychological Test Results

5.3.1. Immediate Auditory Memory

Contrary to previous research (Peters et al., 1977; Andrews et al., 1986), that found that divers performed significantly worse than non-diving controls on the WMS logical memory subtest, this study found a statistically significant result in the opposite direction. The sport divers in this study performed better than both the rescue diver and the control group in immediate recall. However, this result can potentially be explained by the higher level of education in the sport diver group, and also by the fact that the subject matter in the subtest is likely to be more familiar to this group. A regression analysis was performed to assess the possibility that the result could be explained by education, and was found to be significant, supporting the contention that the differences in performance on this test were due to differing education rather than group membership.

The finding is consistent with research by Williamson, Clarke and Edmonds (1987), which found that abalone divers performed as well as or better than non-divers in immediate memory, although a different test (WMS paired associates) was used. By contrast, Cordes et al. (2000) found that divers performed significantly worse than non-divers on the first trial of the WMS paired associates test.

No significant differences were found on either the RAVLT (immediate recall and List B), or the Digit span (Forward, WMS) tests. These are more culture-fair tests, suggesting that the result on logical memory was probably due to culture and educational level rather than superior memory on the part of the sport divers. Tetzlaff (1999) also found no significant differences on immediate recall, although the authors used a different test (Buschke's selective reminding test).

Peters et al. (1977) found a significant difference between a group of neoropsychologically impaired divers and an unimpaired diving control group on the WMS digit span subtest, however the divers in that study were assigned to the impaired or control group based upon their cognitive performance, making a systematic bias almost inevitable. Both Bast-Petterson (1999) and Cordes et al. (2000) were unable to establish any significant difference between divers and non-diving controls using the

WMS digit span subtest. This study was likewise unable to establish significant between group differences on the digit span (forward, WMS) subtest.

5.3.2. Delayed Auditory Memory

Once again contrary to previous research (Peters et al., 1977; Andrews et al., 1986), the sport divers significantly outperformed both the rescue divers and the non-divers in the delayed recall of the logical memory subtest (WMS). Again, this is likely to be due to the effects of education and culture. Williamson, Clarke and Edmonds (1987) also found that divers outperformed non-divers in delayed recall, although the test used was a different one (paired associates) from the WMS battery. Although Todnem, Nyland, Kambestad and Aarli (1990) found that divers performed significantly worse than controls in auditory memory, some of the subjects in this study had suffered DCI, and the finding was independently correlated with history of DCI.

In the current study, none of the groups deteriorated markedly in the delayed recall, obtaining very similar scores to those obtained on immediate recall, suggesting no memory deficit. The correlation between performance on WMS immediate and delayed recall was calculated, and was found to be highly significant. This suggests that the groups performed equally well on the Immediate and Delayed recall, indicating that no difficulties in long-term memory were experienced by any of the participants.

No significant results were obtained for the RAVLT recall and recognition trials, suggesting that there was no real difference between the delayed auditory memory of the three groups. This is consistent with the non-significant finding of Tetzlaff et al. (1999) on the delayed recall and recognition trials of Buschke's selective reminding test.

Therefore, this study did not find any memory difficulties in either of the two groups of divers, which is consistent with previous research on divers without a history of DCI.

5.3.3. Immediate Visual Memory

The sport diver group once again outperformed the control group, although not the rescue diver group, on incidental recall of the Rey CFT. This is in contrast with previous research (Andrews et al., 1986; Bast-Pettersen, 1999, Tetzlaff et al., 1999), which found no significant differences on this measure. Once again, it is suggested that the difference in performance should be attributed to different educational levels, and this contention is supported by the regression analysis.

5.3.4. Delayed Visual Memory

No significant differences were found between the groups on the delayed visual memory measure of the Rey CFT. This is inconsistent with previous research (Tetzlaff et al., 1999), which found a significant difference between a group of elderly divers and controls. The results of the independent samples T-test proved that there were no significant differences in performance on the incidental and delayed recall trials, suggesting that none of the groups in the current study experienced difficulty with delayed visual memory.

Since the sport divers significantly outperformed the other two groups on immediate recall, it could be argued that they experienced a greater decrement in performance than the other two groups, but this is purely speculative. Another possibility is that this difference will become more significant as the sport divers age.

5.3.5. Tracking

No significant differences between the groups were found on any of the three tests of mental tracking (RAVLT repetitions, Digit span backwards or TMTB). This is consistent with the finding of Fueredi, Czarnecki and Kindwall (1991) and Bast-Pettersen (1999), but contradicts the results of Peters, Levin and Kelly (1977). The methodological flaws of this study have already been discussed. Tetzlaff et al. (1999) also found that divers performed significantly worse than controls on TMTB, but as mentioned previously, this study was on elderly divers, who had much more diving experience, so were more likely to have experienced cognitive decline.

Unfortunately, this study erroneously used the intermediate, rather than the adult, version of the TMT. Had the correct version been used, it is possible that significant results may have been obtained.

5.3.6. Motor Speed

Previous studies (Andrews et al., 1986; Fueredi Czarnecki and Kindwall, 1991; Bast-Petterson, 1999) failed to find significant differences between divers and controls on the Symbol Digit Modalities Test (SDMT). However, the current study found that both the sport and the rescue divers significantly outperformed the control group on this measure. This could be supportive of the contention by Williamson, Clarke and Edmonds (1987) that divers tend to perform faster on tests of motor speed because they sacrifice accuracy for speed. However, this needs to be further researched since the instruction given on the SDMT (as suggested in the instruction manual, Smith, 1982) was not to correct any errors, but to continue because speed was of paramount importance.

The Trail Making Test part A did not significantly discriminate between the three groups. This was consistent with the TMTA results reported by previous studies (Fueredi et al., 1991; Bast-Petterson, 1999; Tetzlaff et al., 1999). Williamson, Clarke and Edmonds (1987) have suggested that potentially dangerous occupations like abalone diving attract a risk-taking population. The same could possibly be said of people who undertake sport and rescue diving. The results of this test could reflect this performance bias. Performance on tests that could be influenced by motivational differences, such as reaction time tests, could be confounded by the use of different strategies so that deterioration in neurobehavioural functioning is difficult to detect. This could have resulted in the non-significant findings in the motor speed tests.

While Peters et al. (1977) found a significant difference on the TMTA; the methodological flaw discussed above should be borne in mind. Since the incorrect version of the test was used in this study, interpretation of the findings is problematic.

5.3.7. Insight and Judgement

Bast-Pettersen (1999) and Cordes et al. (2000) found no significant difference between groups on the Similarities subtest. This conflicts with the current study, which found that the sport divers significantly outperformed the non-divers. It is suggested that this difference is due to educational level rather than group membership, and this contention was supported by the results of the stepwise regression procedure, which found that educational level was the best predictor of performance on the Similarities test.

No previous studies have used the Comprehension subtest in their research; therefore interpretation of the result is problematic. The current study obtained significant results. In marked contrast to the result on Similarities, the sport diver group performed significantly worse than the rescue diver group, although not the control group, on Comprehension. Lezak (1995) has suggested that education has a significant influence on test performance, and that the test measures social knowledgeability and judgement. The reason for this surprising finding can only be speculated about, particularly since the test was administered in a written rather than a verbal format.

It is possible that the sport divers considered the answers to be obvious and did not elaborate on them, thereby losing points. Another explanation is that the sport divers were more impulsive and less thorough in answering the questions. This style of response would have had no impact on the scores for Similarities since in the majority of cases, only a one-word answer was required. However, the discrepancy was clear in Comprehension, which relies on answers being comprehensively explained. This area would be an interesting one to explore in future research, particularly due to the contention in previous research (Lunn, 2001; Williamson, Clarke and Edmonds, 1987) that diving results in impulsive behaviour.

5.3.8. Word Initiation

This test successfully discriminated between the sport divers and the control group, and was approaching significance between the sport divers and the rescue divers. The sport divers performed significantly worse than the control group on this test. This result is considered to be highly significant, particularly in light of the higher educational level of the sport divers, which should have been to their advantage in this test.

This result is in contrast to the non-significant results found by Andrews et al. (1986) and Cordes et al. (2000). The participants in Cordes et al.'s (2000) study were military divers, so although they had completed many more dives than the group in the current study, they probably have comparably safer diving practices than the sport divers in the current study. There is also the possibility of the "healthy worker effect" selecting out unhealthy divers, which would have biased the results. Nevertheless, the result on the word fluency test in Cordes et al.' s (2000) study approached significance ($p = 0.08$), and the divers were relatively youthful (mean age 38.7), suggesting that a significant result may be obtainable in the future.

In Andrews' et al.'s (1986) study, when the authors correlated dive stress with test performance, they found a significant association ($p = 0.003$) on the COWAT. This suggests that the COWAT was sensitive to deficits in divers with a large amount of dive stress.

Lezak (1995) has indicated that that a reduced capacity to generate words is characteristic of all dementing processes, but is particularly vulnerable to left and bilateral frontal lesions. Raskin (2000) has suggested that people with mild traumatic brain injury are impaired on tests of verbal fluency. The results on this test suggest that sport diving affects ability to initiate words, which is suggestive of a decrement in frontal lobe functioning. This contention requires further research since the other tests of frontal lobe functioning (Similarities, Digit Span, Backwards) did not reveal significant results.

5.4. Limitations of The Current Study and Recommendations

An important weakness in the design of the study was in the selection of subjects to groups. The results of the study may have been strengthened had the samples been better matched in terms of the demographic information collected in the biographical questionnaire, particularly relating to education. The group of sport divers had a significantly higher level of education than the rescue divers and non-diving control group. Sport divers in South Africa tend to be an elite group in terms of education as it is an expensive sport, and this may have biased the results. Future studies should attempt to match the groups for education.

Another weakness, mentioned by Bast-Pettersen (1999), is that fire fighters are a selected group, as they have to pass yearly health examinations in order to continue working for the fire service. Further selection would also occur due to the "'healthy worker effect'" (Bast-Pettersen, 1999, p. 55), as the least suitable and unhealthy people would drop out of the work. Fire fighters are also physically fitter than the average population as it is a job requirement that they exercise four times per week. This could explain the lack of significant findings in the rescue diver group. Cross-sectional studies have been criticised as they underestimate exposure effects due to selection out of diving, either occupationally or for recreation (Bast-Pettersen, 1999). This could have caused the lack of significant findings. A useful study in the future could entail obtaining the names of a group of rescue or sport divers who trained together, and then following them all up, regardless of whether or not they are still diving. This could reveal diving injuries that have been missed due to the selection out of diving.

Since much of the testing was performed on the weekends, it is important to note that the questionnaire did not request any information regarding any alcohol consumption or lack of sleep on the night prior to the testing. This is an important shortcoming, as some of the neuropsychological test results could have been affected by fatigue and hangover symptoms. Future testing should ascertain this important information.

The relative youth of the populations may also be an important factor, since the literature (Calder, 1992; Wilmshurst, 1997; Tetzlaff et al, 1999) suggests that the damage due to diving is cumulative, and may take many years to become apparent. The average ages of the rescue diver and sport diver groups were 31 and 35 respectively. Future research should possibly focus on an older group of sport divers, or a follow-up study could be undertaken on this group to monitor any decrements in performance over time.

The lack of significant findings could be attribute to the inadequacy of the psychometric tests used, as pointed out by Calder (1992). Most of the tests used are not designed to reveal mild cognitive deficits. Also, since the significant result on word initiation appeared to implicate frontal lobe and executive functioning as being the most sensitive to diving, perhaps future testing should focus on frontal lobe functions. The use of subtests from the SAWAIS-R could also be regarded as a weakness of the study, since the test is old, and the questions on Comprehension may be inappropriate or no longer relevant for current use. Both of these tests have been revised in the WAIS III, however this test has not yet been standardised for use with a South African population.

The rescue divers do not dive as frequently as the construction divers investigated in other countries, diving on average only 24 times a year. Their logged hours were consequently quite low, and had the study investigated divers with more logged hours, significant results may have been found. In addition, rescue and sport divers in this study differed with respect to number of dives. The sport divers tested were predominantly master divers who dive every weekend, and had logged an average of 176 dives, compared to the average of 80 dives by rescue divers. Although this difference was not statistically significant, it may have had practical significance. Future studies should investigate at professional divers who dive every day, and who may not follow safe diving practices.

Regarding the method of testing, a weakness of the study was in the conversion of traditionally individually administered tests into a group administration format. This may have adversely affected the motivation of the participants, and some of the differences in performance may have been due to individual differences in effort and motivation. This could be better assessed with individual administration of all of the tests. Another drawback was the use of the original form of the logical memory test (WMS), which may have prejudiced the performance of the subjects due to their unfamiliarity with the content of the stories. Future studies should make use of forms that have been created for the South African population.

Much of the literature (Elliott, 1989; Holden, Morsman and Lane, 1992; Elliott, 1997; Tetzlaff et al., 1999) has suggested a need for longitudinal research into the cognitive effects of diving. Elliott (1997) also suggested a cross-sectional survey of elderly divers and matched controls. Peters, Levin and Kelly (1977) recommended that professional divers have baseline neurobehavioural tests done prior to commencement of diving. Similarly, Tetzlaff et al. (1999) have suggested that divers should undergo prior psychometric testing, and should be periodically reassessed in order to detect any adverse effects from diving.

Another possibility for further research involves in-depth interviews as well as personality testing with the divers, since significant differences were found on the POMS measure and frontal lobe functioning. Specific tests of executive functioning could also be used in further research.

5.5. Conclusion

The differing educational level between the sport divers and the other two groups unfortunately confounded the results of the current study. However, it is still tentatively concluded that there are no significant differences between divers and non-divers, or between rescue and sport divers in the functions of immediate and delayed auditory and visual memory. This is in accord with several previous studies (Andrews et al., 1986; Williamson, Clarke and Edmonds, 1987; Bast-Pettersen, 1999; Cordes et al., 2000), although it contradicts others (Tetzlaff et al, 1999). Conclusions about mental tracking cannot be drawn due to the usage of the incorrect version of the TMTB.

Significant differences were found in motor speed, with both diving groups displaying significantly faster performances. Again, this result has been supported by research (Williamson, Clarke and Edmonds, 1987), but the reason for this result should be explored further. The other test of motor speed used (TMTA) was inconclusive due to the use of the incorrect version of the test.

The hypothesis of a global deterioration of functioning, suggested by several authors (Wilmshurst, 1997; Calder, 1992) has not been supported by this study. This could be due to the inadequacy of the tests used to detect mild cognitive impairment.

Significantly poorer results were obtained by the sport divers on the insight and judgement measure of Comprehension, as well as the initiation measure of word fluency. Since both of these are tests of frontal lobe functioning, it is tentatively suggested that sport diving, with its associated risk factors, may lead to decrements in frontal lobe functioning. Another possibility is that diving leads to global decrements in functioning, but that tests of frontal lobe functioning are most sensitive to this and consequently are the first to discriminate. However, since other tests of frontal lobe functioning (Similarities, Digit span Backward) did not produce significant results, this result should be interpreted with caution, and further investigation is necessary before a definite conclusion may be reached.

It appears that rescue divers, who engage in safe diving practice, are afforded a measure of protection from cognitive damage. However, this contention cannot be extrapolated to other populations of divers who have completed significantly more dives, since a deficit may become apparent at a later stage due to advancing age or increased diving experience.

It is suggested that sport divers make use of the conservative decompression procedures recommended by Moon and Vann (1995), of a slower rate of ascent and a safety stop at six metres, in order to allow for degassing and prevent bubble formation.

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APPENDIX 1: BIOGRAPHICAL QUESTIONNAIRE

BIOGRAPHICAL QUESTIONNAIRE

Name ______________________________

Age______________________________

Gender ______________________________

Highest standard passed at school________________

Further qualifications______________________

Total years of education____________________

Occupation____________________________

Have you ever had a head injury/concussion/lost consciousness (Y/N) ________

Details of above____________________________________

____

Have you ever suffered from decompression sickness?________________

Details of above____________________________________

____

How many units of alcohol do you consume a week?________________

Do you smoke?(Y/N)____________________

How frequently do you exercise?____________________

How long have you been diving for?____________________

Approximately how many dives have you done?____________________

How often do you dive?____________________

How deep was your deepest dive?____________________

How deep do you normally dive?____________________

How many units of alcohol, if any, would you consume before a dive?__________

How many units of alcohol, if any, would you consume after a dive?__________

What is your body weight?____________________

What is your height?____________________

Do you adhere to the dive tables?____________________

Do you use a dive computer?____________________

When was your last dive?____________________

APPENDIX 2: PROFILE OF MOOD STATES QUESTIONNAIRE

APPENDIX 3: CONSENT FORM

CONSENT FORM

I, ... Declare that

A)

1. It has been explained to me that I will complete psychometric (paper and pen) tests
2. I have been informed that all the information will be treated as confidential, but will be used for a Masters' thesis, and may be published in a psychological journal. My name will not appear in either document, and it will not be possible to identify me.
3. I will have access to the results should I so desire.

B)

I hereby give my voluntary permission to participate in the above-mentioned project.

Signed at .... on............................2002.

Signature.............................