Investigating the relationship between simulated depth, cognitive function and metacognitive awareness.

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Investigating the relationship between simulated depth, cognitive function and metacognitive awareness.

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This report describes a pilot study aimed at identifying the cognitive and metacognitive effects of simulated depth. The population studied were one hundred and three SCUBA divers recruited from the general diving population.

The primary aim was to determine if people can tell when their performance is being affected by nitrogen narcosis. A secondary aim was to investigate demographic factors which may have affected an individual's ability to identify a change in their performance.

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1 SUMMARY

Both susceptibility to and awareness of performance impairment in hyperbaric environments is of recognised interest. Past research, using small samples in uncontrolled conditions, identified changes in psychometric performance during exposure to hyperbaric environments, but not differences in divers' perception of, and actual change in, performance. This study investigates the level of awareness in divers by replicating these tasks in controlled environments.

Divers were recruited from the United Kingdom diving community, reflecting age and gender spread within this population. 103 participants completed a computer-based task battery containing 4 cognitive measures (Reaction Time, Motion Tracking, Long Term Memory, Letter Rotation), designed to evaluate varying levels of cognitive function. Psychometric data were analysed with Repeated Measures ANOVA and Bonferroni post hoc pair-wise comparison. Metacognitive judgements were analysed with Wilcoxon's signed rank test.

No cognitive deficit was detected with increasing pressure. Metacognitive data indicated that at 5 ATA, participants perceived their performance would be worse ($P \leq 0.01$) than at 1 ATA on the Reaction Time task. After the task, the participants believed their performance to be no different at 5 ATA to 1 ATA. This trend reversed with the Long Term Memory task. Participants perceived they would perform better ($P \leq 0.03$) at 5 ATA than at 1 ATA.

Participants may concentrate more on tasks whilst under pressure, thereby performing more successfully. Participants' confidences in their abilities were affected by hyperbaric pressures. At 5 ATA, light cognitive tasks showed reductions in confidence prior to the task, whereas, demanding tasks showed increasing confidence, indicating subjective judgements should be questioned.

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3 Introduction

3.1 OBJECTIVE

This report describes a pilot study aimed at identifying the cognitive and metacognitive effects of simulated depth. The population studied were one hundred and three SCUBA divers recruited from the general diving population.

3.2 AIMS

The primary aim was to determine if people can tell when their performance is being affected by nitrogen narcosis. A secondary aim was to investigate demographic factors which may have affected an individual's ability to identify a change in their performance.

3.3 BACKGROUND

Nitrogen narcosis (from now on referred to as narcosis) is a concept that is well known to all divers, yet in research terms remains an ill-defined and inadequately understood phenomenon (Jennings, 1968; Fowler, 1972; Drew, Lythgoe, & Wood, 1976; Sparrow, Mathieu, Wattel, Lancry & Neviere, 2000). No pathophysiology has been established and an accurate depth of onset never satisfactorily proven. The result is confusion about when the effects of narcosis are to be expected.

The confusing and contradictory findings of research examining physiological and psychometric tests (Bennett, 1999; Frankenhaeuser, Graff-Lonnevig & Hesser, 1963; Kiessling, & Maag, 1962; Lippman, 1996; Petri, 2003) has led to the situation where divers are aware of the existence of narcosis, but may believe that narcosis applies to divers other than themselves. This could reflect the fact that either there are wide individual variations in onset, or divers have little insight into the behavioural manifestations of narcosis seen in themselves during diving. The safety implications of divers being unaware of their state of narcosis were the major focus of this study. Commercially trained divers often believe that due to their experience they are able to perform as well as normal, even while suffering from narcotic effects (this is often referred to as 'adaptation'; Ono & O'Reilly, 1971).

Anecdotal reports indicate that divers believe themselves to experience narcosis at different depths. Some divers report no narcosis at all, whilst others report narcosis occurring at depths of less than 30m. Divers also report experiencing narcosis at different depths on different occasions i.e. they may believe that they experience narcosis at 30m on one dive and at 50m on another.

One explanation for the variability in reporting narcosis is that divers may not be aware of the effects of narcosis at the time. All divers (particularly commercial divers) may have learnt to adapt to extreme conditions. It is also possible that objective measures of behavioural impairment would indicate a narcotic effect whilst the divers are unaware of such deficits. This is akin to the heavy drinker who believes that alcohol has no effect on their ability to drive yet who nonetheless drives dangerously (Monterio, *et al*, 1996).

A number of researchers have reported evidence that narcosis affects cognitive function (Bennett, Poulton, Carpenter & Catton, 1967; Biersner, 1985; Kiessling & Maag, 1962; Frankenhaeuser, Graff-Lonnevig & Hesser, 1963; Davis, Osborne, Baddeley & Graham, 1972; Osborne & Davis, 1976; Synodinos, 1976; Baddeley, 1971; Sparrow, Mathieu, Wattel, Lancry, & Neviere, 2000; Petri, 2003). However, to our knowledge this is the first time that a large group of recreational divers have been studied. Much of the previous research was performed on small numbers, in many cases less than 15 participants, and in many cases the participants used were not either divers or familiar with the hyperbaric environment. In some studies the participants were of mixed ability and experience, whilst some used navy personnel, but most relied on "fit young males". Also the past researchers did not investigate the question of whether divers are aware of such effects *at the time they are diving.* They may be aware that narcosis can occur but believe that they personally are not experiencing it at the time, or that upon surfacing they do not remember experiencing narcotic effects. This factor is of considerable importance in relation to the diving industry. Narcosis may act as an additive factor increasing the likelihood of a minor incident developing into a life-threatening situation. Divers *may* believe that they will not experience narcosis until they reach a specific depth (e.g. 30m as in *Sport Diving*, BSAC Manual 1991, or 28m Sisman 1982 [The Professional Diver's Handbook]) and so be biased against awareness of narcosis at shallower depths. Bevan (1982) stated that "*there is a progressive reduction in thinking ability as divers go deep on air.*" and that "*this affects every diver without exception*", but that it is "*not noticeable until it is necessary to work out a task*". Even then, they may believe the task to be especially difficult, not that they are impaired. It could also be that divers believe that they have adapted to working/performing tasks at pressure and, therefore, deny or not realise how their motor and cognitive functions are impaired. Mount and Milner (1965) described a study in which divers were told to expect narcosis at different depths (10m or 25m); this is precisely what the divers reported. The group told to expect narcosis at 10m reported narcosis at this depth, whilst the 25m group did not report narcotic effects until the 25m depth. Given that it is unlikely that actual behavioural measures differed between the groups, this evidence clearly indicates that divers were not aware of their true level of impairment. The findings highlighted by this study will have significant relevance for diver safety. The 25m group have been grossly overestimated their ability to cope with the dangers of diving because they did not believe they were suffering from the effects of narcosis, despite evidence to the contrary. The findings of Mount and Milner (1965) suggest that there could be issues of conformity (Jenness, 1932; Sherif, 1935) where the essence of the problem could be *'a change in a person's behaviour or opinions as a result of real or imagined pressure from a person or group of people*' (Aronson et al., 1978) or in diving environments, buddies and instructors.

Awareness of one's level of cognitive performance has been studied widely by cognitive psychologists under the title '*metacognition*' (Metcalfe & Shimamura, 1994) but has never been studied in relation to the effects of hyperbaric air. Metacognition refers to:

- the subjects' declarative knowledge about cognition, and about their own cognitive activities and capacities,
- procedural knowledge or processes that may be activated in order to control and regulate one's own thinking (knowing about knowing).

The ability to know that you know is invaluable. If this skill is lost it can lead not only to the sufferer denying their lack of coping ability but also to lapses of safety. This study has been the first systematic examination of divers' awareness of their level of narcotic impairment. Our intention was to establish the level of impairment on a range of cognitive tests at specific depths simulated in a hyperbaric chamber. This entailed measuring reaction times and, to a limited extent, motor ability. Although these tasks do not exactly mimic actual tasks a diver is required to do, the data obtained provides us with clear and explicit indications of the degree of impairment a diver is likely to experience. We also tested the divers' level of awareness of performance at each of the test depths.

4 Materials and Methods

4.1 HARDWARE:

In this type of study it is important to understand the hardware being used in order to standardise the participants experience and also to allow the study to be accurately replicated in the future.

Chamber was at the top of a set of steps and no elevator facilities were available.
1 comex 1800 chamber
Chamber entrance is a circular hole 610mm in diameter and 390mm from the external deck plate.
2 Advent desk top computers, Pentium 4, 32 Mb Graphics card (located outside, but next to the chamber)
1 Table (715mm x 1700mm x 585mm)
2 Two button computer mice
2 Chalco Eleven Chamber Monitor CCM-1550-04
2 Compressed rubber mouse mats (410mm x 305mm)
3 Polyprop stools (495mm x 355mm x 295mm)
1 divider curtain use to separate the participants during the testing phase.

4.2 SOFTWARE:

Windows XP Professional – (including Direct X version 9.00)
Task Battery Design for the trial containing four psychometric tasks and metacognitive assessment questions.

4.3 PSYCHOMETRIC TASKS:

A series of four computer-administered psychometric tasks were developed by the research team in collaboration with the Psychology department at the University of Plymouth. The tasks were selected to assess different levels of cognitive function (See section 2.4 for descriptions of task parameters) necessary to perform competently and safely in a complex working environment. These tasks were also selected because they provided a rigorous test battery which could be performed in a set time, allowing safe decompression schedules to be developed for the chamber dives.

Reaction Time (RT)
Motion Tracking (MT),
Letter Rotation (LR),
Word Pair Recall (WP)

These tasks had, in previous studies, shown narcosis to cause cognitive impairment (Moeller et al, 1975, 1981; Whitaker & Findley, 1977), although in previous research, Letter Rotation and Word Pair Recall had been measured using paper-based tests. A computerised task is no more or no less than the sum of its items, as is the case with traditional psychometric tasks. However it is possible, in principle, to use items that could not be presented other than by computer. Obvious examples in this research were the use of reaction time and tracking tasks. A computer test, even if it consists of what might be called computer-bound items (Kline, 2000), must still be judged against the standard psychometric criteria of reliability, discriminatory power, validity and the quality of normative data, where these are applicable.

It is possible to computerise virtually any traditional psychometric test. It is far easier to present on the computer screen verbal and numerical items than visual items. There is always the possibility that the screen image will be different from the printed image, even with modern graphics and other instruments such as light-sensitive pens. Nevertheless, no matter how identical the two tests appear to be, it is essential that the reliability, validity and standardisation of the computer version be checked. Furthermore, it is essential to show that the correlation between the computer and paper versions is high.

There have been many studies looking at narcosis and traditionally they have used paper based tasks (Moeller et al, 1975, 1981; Whitaker & Findley, 1977) although there has never been a consensus in the field about the appropriateness of a task or the need for study replication to confirm the findings. The four tasks selected in this research, have been shown to require different levels of cognitive processing in order to perform well on them (Fowler & Granger, 1981; Dickson, Labersten, & Cassil, 1971). They were also selected so that they might be easily transferable to everyday life situations and then in turn to diving.

Due to this change in technology and presentation, it is not possible to compare precisely the results obtained from this study with those of the past, as there are potentially significant differences in such aspects as their visual resolution and their data sampling rates. It is likely that the data collected during this research is more accurate (higher number of significant figures) than that of past studies. In Moeller & Chattin (1975), participants' responses were transmitted from transducers mounted on the desk top to control and recording devices located outside the chamber, they used an adaptive tracking task that the participants responded to via a pressure sensitive controller. This is not unlike the motion tracking task in this study where responses were recorded and achieved through the motion of a mouse connected to a computer located outside the chamber. This study has chosen to utilise modern computer technology which is widely available to most individuals to present the tasks in a format that they are familiar with.

Reaction Time tasks are commonly used in research and are understood by the general public as the time it takes for an almost reflex action, for example in a diving environment this could be the time from recognising a free flowing regulator to taking action to stop it.

Motion Tracking is a hand-eye co-ordination task. Following the example for RT further; you may be able to start the action of securing the free flowing regulator, but if you can not coordinate you hand and eye movements then you will have great difficulty catching it.

Word Pairs task can be taken in three sections relating to memory: 1) *registration* (reception); 2) *storage*; and 3) *retrieval*. The main area assessed in this study is that of retrieval. It is recognised that retrieval can only occur with data what has been received and stored, or in a real world situation 'shown' and 'learnt'. The task was therefore piloted to ensure that the number of word pairs used was not so great that they simply did not register, and that they were shown for a sufficient period of time to allow them to be stored. This turned out to be twenty pairs of words each shown for four seconds. This task therefore assessed the retrieval of data which is an important facet of psychological functioning in that it allows us to recall important and salient information at appropriate times which we can therefore use to solve or prevent problems. Using the free flowing regulator metaphor, this would be akin to remembering your training regarding free flows and then performing the correct actions to resolve it.

Letter Rotation assesses the ability to orient one's self and recognise patterns in ones' surroundings or more specifically with the visual stimulus presented. This is of course especially important in the 3D world of diving. It requires a judgement regarding the correct orientation and the recognition of an objects relation to another similar pattern and then a judgement as to the similarity of the objects. For example if a diver drops a piece of equipment, knowing which way it will fall and where it might be found could be vital for the safety of an operation.

The tests chosen in this research differ from much of the past research, not only due to their administration by computer, but also because it allows tasks to be presented to each individual in a standardised way and transferred for analysis with much less likelihood for errors.

The data from the tasks themselves should also be more accurate than that collected in past research that has had to rely on a second person timing responses and judgements. Apart from the motion tracking task, a timing element was present in all the tasks. The use of a computer allows a massive amount of accurate data to be produced. The Motion Tracking task as presented in this research can only be administered the tasks via a computer. It has allowed us to look at the possibility of trade offs between fulfilling the task (keeping one circle inside another) and the effort made to fulfil the task (how close to the centre of the circle they kept the smaller circle) over the time period.

4.4 PSYCHOMETRIC TASK PARAMETERS

The font for the general text is all 'Arial' font size '20'.

Reaction Time: the task had 60 trials with a minimum interval of 200 milliseconds and a maximum interval of 2000 milliseconds between the randomly presented stimuli. The stimulus was a white dot font size 30 presented on a black background. The participants responded by clicking the left hand mouse button (on a two button mouse).

Motion Tracking: The largest target radius is 50 millimetres and the pointer radius is 4 millimetres. The target radius decreases by a factor of 0.88 on eight equal intervals over the duration of the task (120000 milliseconds). The background is black and the target and pointer radius are green while the pointer is inside the target, and red when the pointer is outside the target radius. The participants respond by moving the mouse to co-ordinate with the stimuli on screen.

Letter Rotation: This task had 64 trials with a 500 millisecond interval between the trials, which timeout after 4000 milliseconds. The trials were broken down into four different types of presentation with sixteen different variations of angles. The participants respond by clicking the left hand mouse button for a pair that is the 'same' (either both mirrored, or both normally presented) as the prior presentation and the right hand button for those pairs that are 'different'.

Left hand 'R'	Right hand 'R'
Normally presented	Normally presented
Normally presented	Mirror reflection
Mirror reflection	Normally presented
Mirror reflection	Mirror reflection

Word Pairs: 20 pairs of words are presented for 4000 milliseconds with a 750 millisecond interval between presentations. The participants then perform the motion tracking task. The participants are then presented with a further twenty pairs of words, some of which are the same as the prior presentation and some a different pairing. These words are presented for a maximum of 5000 milliseconds (timing out after this point), with a 500 millisecond interval between word pairs. The participants respond by clicking the left hand mouse button for a pair that is the 'same' as the prior presentation and the right hand button for those pairs that are 'different'.

Metacognitive measure: Prior to the participants commencing any of the tasks they were asked to rate how well they thought they were going to perform. The rating was achieved by manipulating an arrow (with the computer mouse) along an analogue scale from '0' very poorly to '100' very well. Once the arrow was in an appropriate place the participants clicked the left mouse button to select that position. At the end of the task the participants were asked to rate how well they thought they had done. This was achieved in the same fashion, but instead of the question being 'how well do you think you will do…?' it was 'how well do you think you did….?'

An important issue in serial neuropsychology investigations is whether a change in performance from test to retest is meaningful. For many neuropsychological tests, decisions regarding the significance of any cognitive change observed may be obscured by practice effects, which act to enhance test performance following repeated exposure to testing procedures and stimuli. Accordingly, many studies have sought to determine the effects of practice on neuropsychological test performance at test-retest intervals of weeks, months or years (e.g., Benedict & Zgaljardic, 1998; Duff et al., 2001). These studies have also sought to determine the extent to which practice effects operate on tests of different cognitive functions. Some authors suggest that practice effects operate equally across different cognitive tests (McCaffrey et al., 1992; Mitrushina & Satz, 1991). However, others show that tests requiring complex cognitive processing, and tests where formulation of a strategy may aid performance, display greater practice effects than tests that measure more simple cognitive functions (e.g., Wisconsin Card Sorting Test, Stroop Test; Basso et al., 1999).

4.5 DEMOGRAPHIC DATA RECORDED FOR EACH PARTICIPANT:

Age
Gender
Medical History
Diving Experience

4.6 ETHICS

The study had ethical approval from 'Independent Ethical Committee (IEC)' Phase 1 Clinical Trials Unit. This ethics committee meets ICH GCP (Good Clinical Practice) guidelines for IEC's and is convened for the purpose of approving studies involving healthy volunteers.

4.7 PILOTING STUDY METHODOLOGY

The study was preceded by a pilot designed to test the feasibility of the proposed methods and procedures. Twenty-four participants were studied. Analysis of their data allowed the psychometric tasks to be fine tuned to remove floor, ceiling and practice effects. Procedural changes were made such as shortening the dive profiles and cooling the chamber between task batteries.

It was also clear from the piloting stage that the participants required practice on the psychometric tasks prior to the experimental assessment. The addition of two practice runs was the only methodological change made.

Power calculations on size effect had previously been performed to determine the number of participants required to perform this research.

4.8 PARTICIPANTS

Power calculations were performed using size effects from previous narcosis research (Fowler, & Ackles, 1972; Hesser, 1963; Undersea Medical Society, 1983) to determine an approximate sample size for this research. Due to adverse events during the performance of the project, we recruited one hundred and three people. This was seventeen participants short of our intended sample size, but following consultation with a statistician it was determined that the sample size was sufficient to provide the power required for the analysis of the data.

Recruitment was done through the DDRC website; posters sent to all local (Devon and Cornwall) dive shops; DDRC open days and presentations. The recruits were consented following standard British Psychological Society (BPS) Guidelines. These were balanced to match national age and gender demographics for SCUBA diving. This data was obtained from the British Sub Aqua Club (BSAC) and Professional Association of Diving Instructors (PADI). The age and gender split can be seen in chart 1 below, but the average age across the whole female group was 32.31 years (Std Deviation, 9.83) and the male group was 35.69 (std Deviation 11.32).

Chart 1:

Age Group		N	Mean	Std Deviation	Median	Minimum	Maximum
18 - 21	Male	8	19.67	0.52	20	19	20
	Female	5	20.60	0.55	21	20	21
22 - 30	Male	17	25.65	2.87	26	22	30
	Female	9	26.11	2.42	27	23	29
31 - 40	Male	26	35.54	2.79	35	31	40
	Female	10	35.40	3.53	35.5	31	40
41 - 50	Male	14	45.60	2.50	44.5	42	50
	Female	5	47.67	2.52	48	45	50
51 - 60	Male	7	55.71	2.81	55	51	59
	Female	2	51.00	0.00	51	51	51
60 +	Male	1	67.00	N/A	N/A	N/A	N/A
	Female	0					
Total	Male	73	35.69	11.32	35	19	67
	Female	31	32.31	9.83	31	20	51

The participants were also asked to provide information on their level of diving experience. This was used to select participants that had a range of diving experience (Number of divers performed, not level of qualification attained) (Chart 2 shows descriptive data for the number of dives performed by the participants). As can be seen below the males tend to have logged more dives than the female of the same age. The only exception to this is in the youngest age group. All participants spoke English as their first language.

Chart 2:

Age Group		N	Mean number of dives performed	Std Deviation	Median	Minimum	Maximum
18 – 21	Male	8	40	32.08	30.5	9	96
	Female	5	77	98.72	42	6	250
22 – 30	Male	17	404	854.35	107.5	3	3500
	Female	9	87	92.66	62	0	260
31 – 40	Male	26	682	971.89	400	4	4000
	Female	10	311	236.03	350	30	734
41 – 50	Male	14	1521	1968.12	600	12	5000
	Female	5	752	838.94	600	0	1657
51 – 60	Male	7	1871	2076.81	1000	150	5000
	Female	2	195	148.49	195	90	300
60 +	Male	1	200	N/A	N/A	N/A	N/A
	Female	0					
Total	Male	73	802	1331.47	309.5	3	5000
	Female	31	239	339.38	100	0	1657

4.9 EVALUATION

All participants answered a questionnaire to collect information on a number of factors:

- Medical. This was either a BSAC self certification for participants under the age of fifty, or a BSAC sports diver medical for those over fifty. A number of the participants held a current Health and Safety Executive (HSE) recognised medical and a copy of this medical was taken from those individuals. Those with current HSE medicals were not required to complete a BSAC form.
- All participants were asked if they had undertaken a ‘chamber dive’ previously and all were briefed on what to expect and various techniques that could be used to equalise their ears during compression. They were informed of the environmental changes that they could expect and the safety requirements and procedures to regard during their time in the chamber. They were also briefed on chamber safety practices and procedures.

4.10 PROCEDURE

On arrival at DDRC, participants were asked to provide a copy of their certificate of medical fitness to dive, or to complete a BSAC self certification of fitness to dive. This was then signed off by one of DDRC’s physicians, or if over fifty years of age a BSAC sport medical was performed. Participants considered not fit to dive were not eligible to take part in the study. Five males between forty-five and sixty-five were considered not fit. All were advised by one of the DDRC physicians and all were advised to consult their general practitioner .

Participants eligible for inclusion were then asked to read the Participant Information Sheet (Appendix 1) and any questions that they had were answered by a member of the research team. Once the participants were happy with the contents of the information sheet they signed the Participant Consent Form (Appendix 2) which was then counter-signed by the researcher in their presence. The participants subsequently completed a questionnaire designed to elicit information regarding their diving practice, qualifications and experiences (Appendix 3).

The study was designed to assess two participants at a time. The participants sat approximately 780mm apart, in the same position on each testing occasion and separated by a white sheet, fabricated to conform to the shape of the chamber and ensure that they were not seen by the other participant in the chamber. It was ensured that the participants sat in the same chair on each testing occasion. The participants sat side by side (see picture section 2.1) rather than back to back.

The participants were briefed using a standardised format (Appendix 4). In a traditional psychometric task, it is essential that the instructions are comprehensible to all participants. In a computer-presented task it is similarly essential that the procedures for answering/ responding are clear and easily followed by the participant. If the participants are anxious about working the machine or are making errors as they proceed, or are unable to operate the computer, the study will have failed.

To avoid psychological stress such as anxiety, the majority of participants had never been submitted to pressure in a dry chamber, two practice sessions were completed in the chamber with the door closed and the carbon dioxide scrubber in operation at 1 ATA (1 atmosphere, normal surface pressure).

The task battery required 9 to 14 minutes to complete depending upon the speed of the individual participants' responses. Responses were indicated by pressing one of two mouse buttons, with the exception of motion tracking which required manipulation of the mouse. The metacognitive judgement aspects of this research were integrated computer based analogue scales. This meant that each time the task battery was performed the participant was asked to make judgements on there performance. This allowed for the metacognitive aspect of the study to be controlled in the same manner as the more objective cognitive task battery.

One of the potential confounding effects in this research was hysteresis. This is the affect that a previous condition or treatment can have on the body. In this situation it may be that narcosis is greatest upon reaching depth and then reduces the longer you spend at the depth or vice versa. To reduce the impact of this effect on the study, the presentation order of the tasks was balanced.

On completion of this first surface practice run, the researcher enquired about any problems experienced by the participants during the task battery and addressed any issues raised. The participants were then asked to complete the task battery again under the same conditions as before. Following this the participants were given a fifteen minute break.

The participants were then re-seated and asked to complete the psychometric battery once more whilst on the surface. Following this they were briefed about the compression and the schedule of events once the chamber had reached its maximum depth.

Participants were not told the depth to which they would be diving. However, the compression was ten metres a minute (unless the participants had problems equalising the pressure in their ears). This rate of compression was chosen as it matched the average rate of descent in-water as calculated from 100 sets of dive data collected by DDRC (unpublished data). A qualified DDRC chamber attendant was present in the chamber during all dives. This was to ensure a trained individual was present in case any medical or mechanical incidents occurred during the dive. There were four occurrences of people not being able to clear their ears on descent, one of which led to a grade two barotrauma. On two occasions one of the computers crashed during the tasks at depth, described as ‘adverse events’. The participant on the ‘crashed’ computer sat quietly whilst the second participant completed the task battery. On leaving the chamber, the participant that had not completed the tasks was asked to rearrange another visit to DDRC to undergo testing again. On both occasions this was possible on the following day and the data was collected without further incident.

Once the chamber had reached the intended simulated depth, the participants were asked by the attendant to start the tasks. The attendant had no more contact with the participants until the participants had completed the battery.

On completion of task battery, the chamber was surfaced according to the dive plans (Appendix 5) and the participants debriefed. The participants were not informed of the depth they attained at this time.

The participants returned on another day to perform their second research dive. They were once again seated in the same position as the first dive and asked to perform the task battery at one atmosphere. The second dive following the same procedure as the first. Following this dive the participants were fully debriefed and informed of the depths that they attained during the trial.

Four depths were simulated during this trial; 10, 20, 30 and 40 metres. The trial was designed to allow for the depths to be partially randomised. Participants either undertook ten and thirty metre dives or twenty and forty metre dives, and these were balanced for presentation.

5 Deviations from Protocol

One of the procedural aspects of this study was to test two participants simultaneously. This was not always possible due to personal complications with participants, such as illness, other commitments and lack of transport. Chart 3 indicates the number of participants that performed a dive on their own.

Chart 3

	1st Dive	2nd Dive	No 2nd Dive performed
No. of participants	15	16	12

Only five participants performed both their first and second dives on their own.

Although all participants completed the task battery at the same time of day, there was a variation in the interval between the first and second dive (Mean 17 days; St Dev 26). All participants completed the task battery at the same time each day (i.e. morning, lunch time, afternoon, or evening).

The number of participants that undertook each trial depth and the order in which they experienced the pressures are indicated below (chart 4). Although roughly the same number of people participated in each depth, we can see from the data below that a greater number performed their shallow (10m or 20m) depth first.

Chart 4:

	10 metres	20 metres	30 metres	40 metres
1st Dive	29	26	21	21
2nd Dive	18	20	27	26
Total	47	46	48	47

5.1 ADVERSE EVENTS

Study related, adverse events included four cases of ear clearing problems leading to a slowed compression rate, and a grade 2 barotrauma in one participant (previously noted), and two cases of Decompression Illness. No protocol deviations occurred in these incidents and one case was a pain and the other constitutional. In each case the person was participating in a 30 meter dive. The dives had a bottom time of thirteen minutes and staged decompression of 6 minutes at 6 meters and ten minutes at 3 meters, at which point the personnel were on 100% oxygen. The decompression schedule used was a DCIEM 33 meter table, with a bottom time of 25 minutes, the oxygen at 3 meters was added as an extra safety procedure following DDRC protocol. Both people were treated once using a USN Table 6 and on follow up were shown to have no residual symptoms. Following this the decision was made, in consultation with HSE and DCIEM to limit the remainder of the trial to twenty metres.

6 Results

6.1 PRACTICE EFFECT

This study had two practice task batteries and then a third and fourth battery performed at one atmosphere (on the surface) interspersed with simulated pressure tests. The one task that showed evidence of a practice effect was the motion tracking. There was a significant practice effect between the first and second practice trial on the motion tracking task (T-test, P≤ 0.001) and the letter rotation task showed an effect on the number of correct responses (T-test, P≤ 0.033), but these practice effects were not present between any other trial. It is therefore possible to say that any learning requirements of the tasks had been met prior to perform the trial runs on the surface and at depth.

6.2 THE PARTICIPANTS' PERFORMANCE

This battery of tasks administered in this environment detected no evidence of a deterioration of cognitive performance with increasing depth.

Chart 5: Reaction Time Task (ms) –

	N	Minimum	Maximum	Mean	Std. Deviation
First surface trial	102	216.2	409.2	307.1	33.8
Second surface trial	99	217.6	457.1	304.4	36.2
10m first	29	249.0	388.3	301.7	32.5
10m second	18	257.0	441.1	311.8	42.8
20m first	26	232.1	437.2	314.4	45.6
20m second	20	220.2	340.9	296.4	28.5
30m first	21	264.3	365.4	310.0	28.2
30m second	27	260.2	395.0	318.0	34.0
40m first	21	228.7	375.1	306.3	30.9
40m second	26	238.8	477.4	332.1	59.0

Figure 1: Reaction Time Task (ms) -

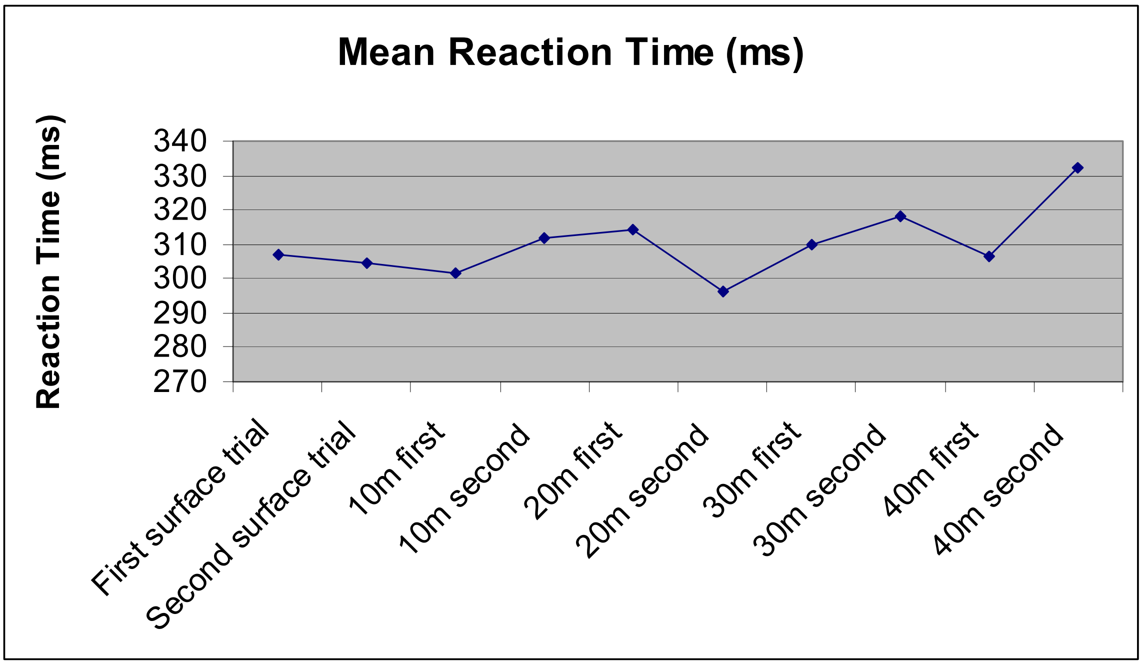


Chart 6: Motion Tracking Task (mm) – Distance from centre of circle

	N	Minimum	Maximum	Mean	Std. Deviation
First surface trial	102	28.0	61.6	37.9	6.5
Second surface trial	98	29.0	58.1	37.6	6.3
10m first	29	29.8	53.4	37.0	6.1
10m second	18	29.0	44.0	36.1	4.0
20m first	26	28.0	61.8	36.0	6.6
20m second	20	29.8	73.7	39.0	10.3
30m first	21	29.0	56.5	37.0	5.9
30m second	27	30.0	52.6	37.9	5.3
40m first	21	29.4	59.4	38.5	7.8
40m second	26	30.7	50.8	36.9	5.4

Chart 7: Motion Tracking Task (secs) – Percentage Time spent inside the circle

	N	Minimum	Maximum	Mean	Std. Deviation
First surface trial	102	31.9	60.4	48.5	6.4
Second surface trial	98	30.2	59.2	48.9	6.3
10m first	29	37.7	58.4	49.5	5.8
10m second	18	40.8	57.4	50.0	4.8
20m first	26	37.1	62.1	50.6	5.4
20m second	20	28.7	57.1	48.0	8.3
30m first	21	37.3	58.3	49.3	5.9
30m second	27	36.7	56.6	48.9	5.2
40m first	21	34.2	57.9	47.5	7.1
40m second	26	37.6	58.7	49.8	5.5

Figure 2: Motion Tacking Task – Time in Circle (ms) and Distance (mm)

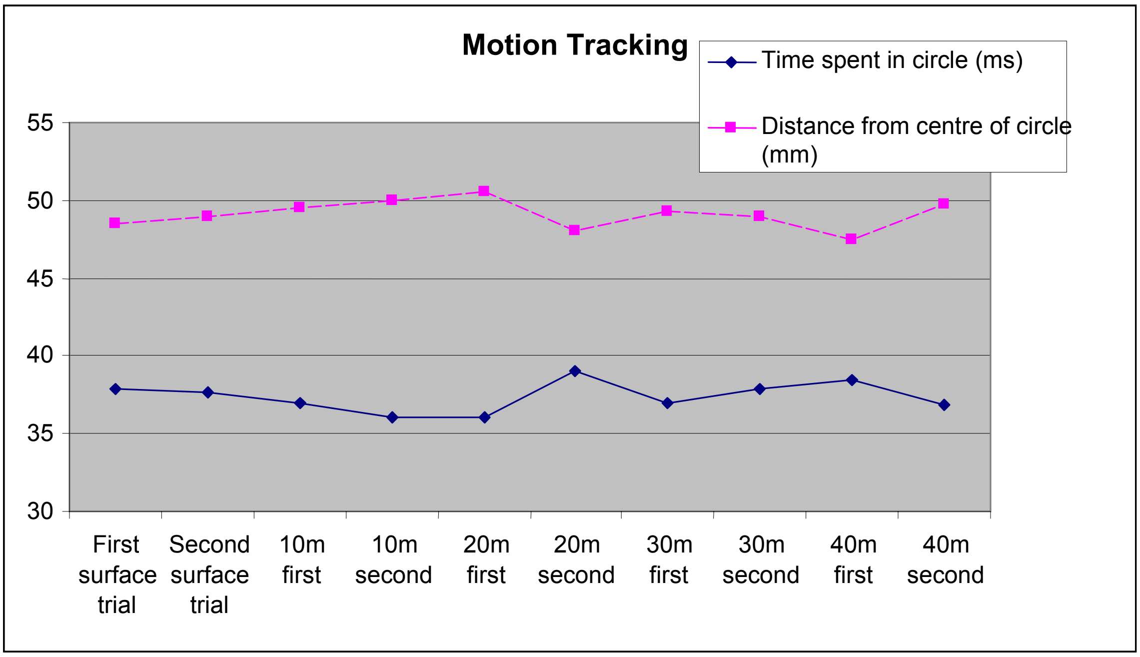


Chart 8: Word Pairs Task – Number of correct responses

	N	Minimum	Maximum	Mean	Std. Deviation
First surface trial	102	5	20	13.7	3.0
Second surface trial	98	8	20	13.6	2.9
10m first	29	8	20	12.9	3.1
10m second	18	7	20	12.9	3.7
20m first	26	7	20	12.7	3.6
20m second	20	6	18	13.0	3.3
30m first	21	2	19	12.0	4.2
30m second	27	5	18	12.7	3.7
40m first	21	6	19	11.9	2.8
40m second	26	9	17	13.3	2.2

Figure 3: Work Pairs Task – Correct Responses

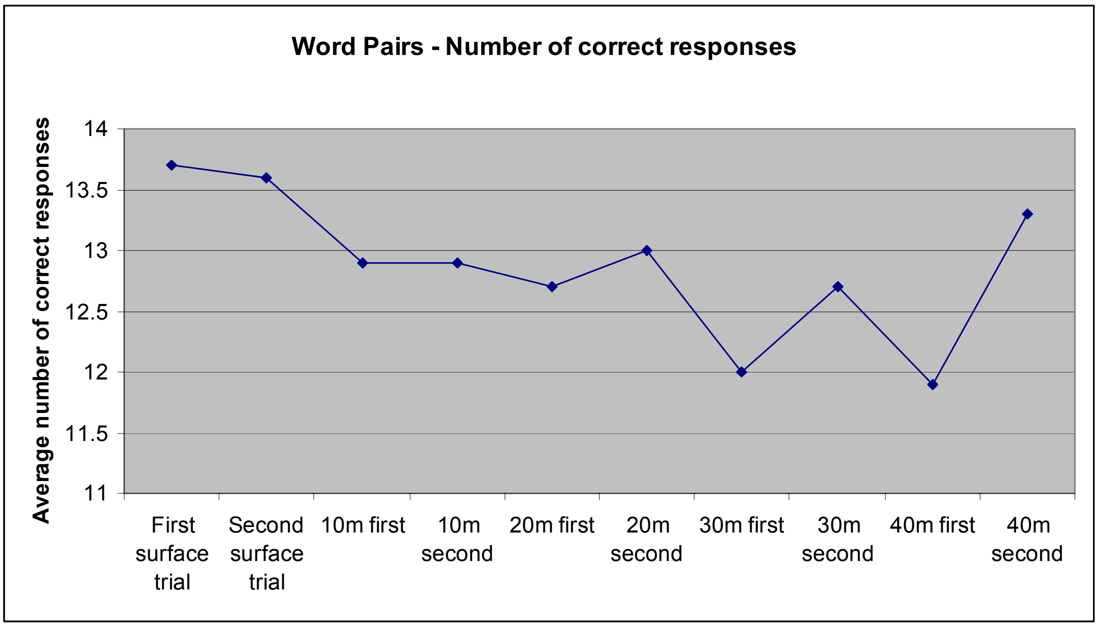


Chart 9: Word Pairs Task (ms) – Reaction Time

	N	Minimum	Maximum	Mean	Std. Deviation
First surface trial	102	704.5	2632.2	1765.3	384.8
Second surface trial	98	1045.4	3353.5	1757.9	401.8
10m first	29	888.5	2454.3	1666.3	419.8
10m second	18	1123.2	2571.1	1727.1	422.4
20m first	26	1151.2	2293.5	1647.3	328.5
20m second	20	1039.0	2340.9	1694.5	431.5
30m first	21	1176.7	2571.1	1830.8	303.5
30m second	27	406.2	2957.5	1525.5	552.6
40m first	21	828.1	2046.9	1571.6	338.8
40m second	26	1091.6	2398.4	1681.6	324.6

Figure 4: Word Pairs Task – reaction time (ms)

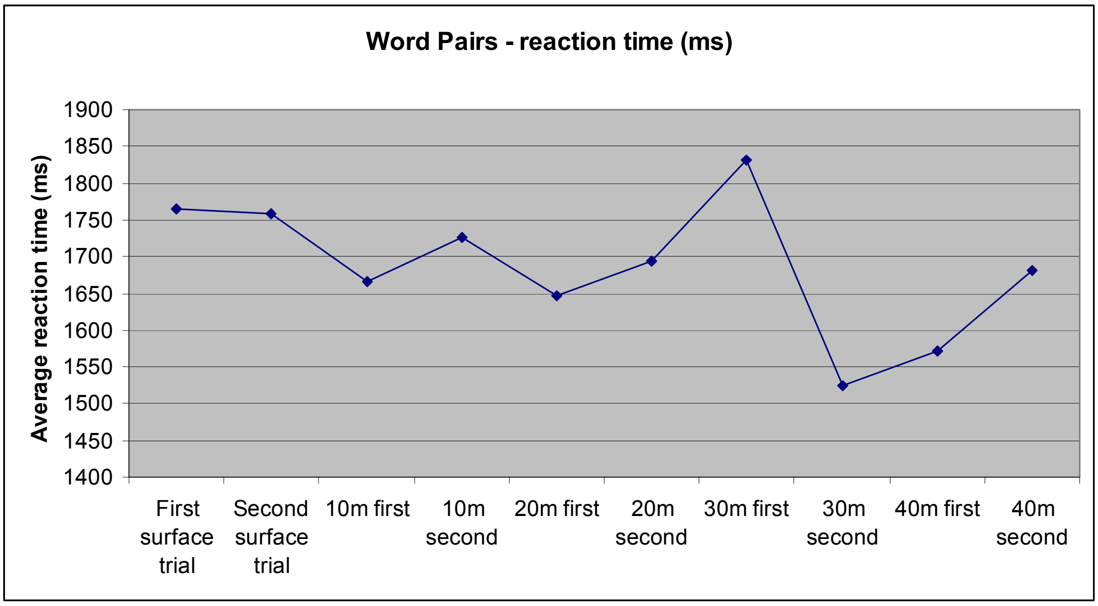


Chart 10: Letter Rotation Task (ms) – Reaction Time

	N	Minimum	Maximum	Mean	Std. Deviation
First surface trial	102	426.5	2225.0	1351.2	310.2
Second surface trial	98	450.4	1888.1	1330.9	258.2
10m first	29	654.0	1718.5	1233.1	277.5
10m second	18	461.4	1784.7	1244.2	335.1
20m first	26	457.8	1883.0	1235.4	306.6
20m second	20	933.2	1509.9	1175.5	182.7
30m first	21	424.5	1819.8	1304.9	386.4
30m second	27	720.4	1885.4	1257.8	252.9
40m first	21	931.2	1696.2	1240.1	196.8
40m second	26	879.8	1649.4	1229.8	184.2

Figure 5: Letter Rotation – Reaction Time (ms)

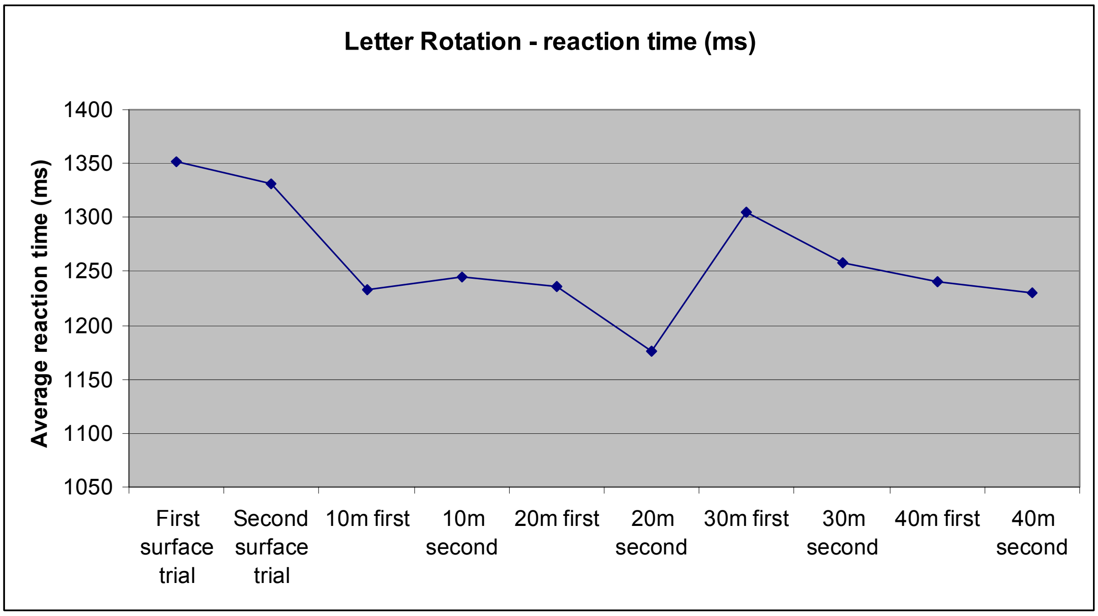
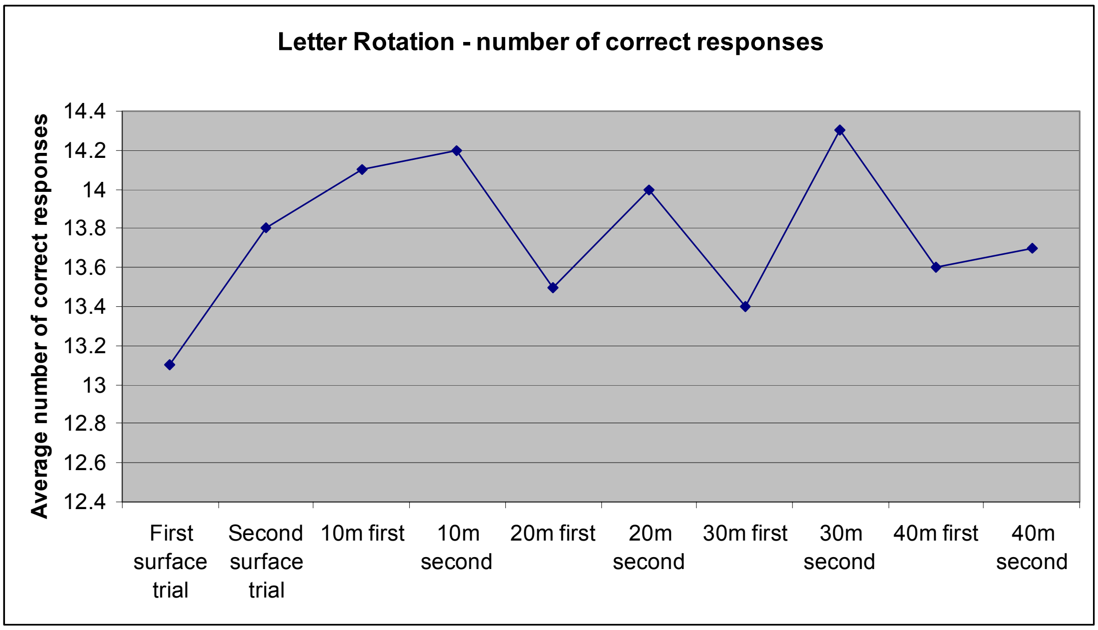


Chart 11: Letter Rotation Task – Number of correct responses

	N	Minimum	Maximum	Mean	Std. Deviation
First surface trial	102	3.3	16	13.1	2.1
Second surface trial	98	3.3	16	13.8	2.1
10m first	29	8.0	16.0	14.1	1.7
10m second	18	10.0	15.8	14.2	1.6
20m first	26	7.8	15.5	13.5	2.0
20m second	20	8.0	15.8	14.0	2.2
30m first	21	4.5	15.8	13.4	2.6
30m second	27	9.5	16.0	14.3	1.6
40m first	21	7.8	15.5	13.6	2.0
40m second	26	8.0	15.8	13.7	1.8

Figure 6: Letter Rotation – correct responses



6.3 PSYCHOMETRIC DATA

Repeated Measures ANOVA with Bonferroni post hoc pair-wise comparison was selected to analyse this data.

Very few significant differences were found within the psychometric data.

The Reaction time task produced a significant ($P \leq 0.005$) decline in performance between surface and 40 metres on the participants' second trial day, but not during the first trial day. It is also worth noting that the significance disappears if the 40 meter data is treated as one group.

The Word Pairs task revealed four significant results. Two differences lay in the number of correct responses given at 30 and 40 metres on the first trial day ($P \leq 0.03$), indicating a decline in the number of correct responses given. The third significant difference is found between the surface and 40 metres on the first trial day, where the participants were significantly ($P \leq 0.04$) faster in their responses. The fourth significance ($P \leq 0.03$) occurs between the surface and 30 metres on the second trial day, where the participants were actually faster at responding to the stimuli.

6.4 METACOGNITIVE DATA

By and large, even though the participants were able to perform as well at 40 metres as they did on the surface, they did not anticipate being able to do so. Upon reaching depth, they were asked if they believed they would be able to perform as well on each task as they had on the surface. The greater the depth, the more likely they were to say that they would do less well. Also, after completing the task, they sometimes said that they thought they had done less well. This suggests that metacognition was affected. When assessing the metacognitive data it was found to be non-normally distributed, we therefore performed a 'Wilcoxon's Test' on this data, using the combined results from the first and second trial day. (Descriptive statistics for these results can be found in Appendix 9).

Chart 12: Reaction Time Pre Task -

	Surface Pre – 10 metres Pre	Surface Pre – 20 metres Pre	Surface Pre– 30 metres Pre	Surface Pre – 40 metres Pre
P - Value	0.604	0.073	0.063	0.007

Chart 13: Reaction Time Post Task -

	Surface Post – 10 metres Post	Surface Post – 20 metres Post	Surface Post – 30 metres Post	Surface Post – 40 metres Post
P- Value	0.754	0.861	0.690	0.056

Figure 7: Pre & Post Metacognitive means for Reaction Time Task

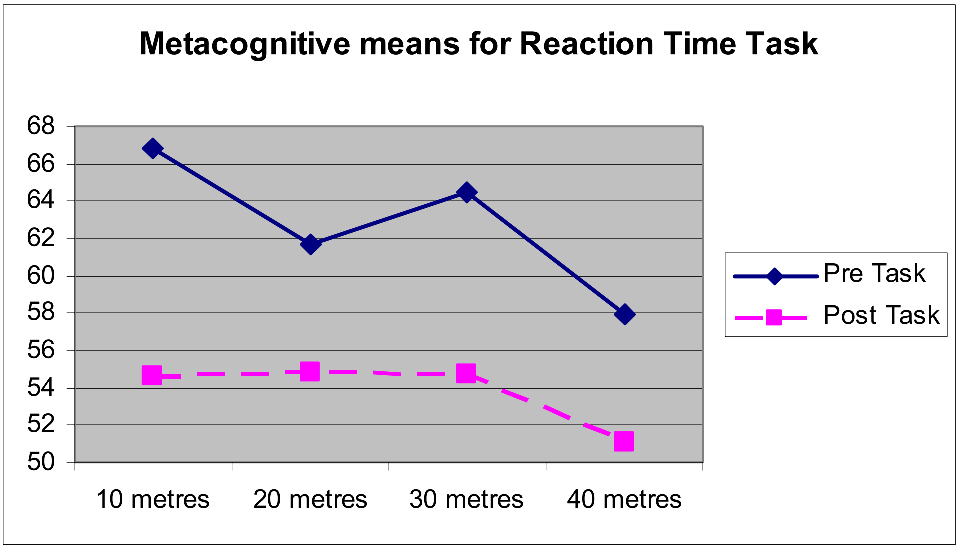


Chart 14: Motion Tracking Pre Task -

	Surface Pre – 10 metres Pre	Surface Pre – 20 metres Pre	Surface Pre– 30 metres Pre	Surface Pre – 40 metres Pre
P-Value	0.459	0.638	0.249	0.044

Chart 15: Motion Tracking Post Task -

	Surface Post – 10 metres Post	Surface Post – 20 metres Post	Surface Post – 30 metres Post	Surface Post – 40 metres Post
P-Value	0.326	0.255	0.586	0.176

Figure 8: Pre & Post Metacognitive means for Motion Tracking Task

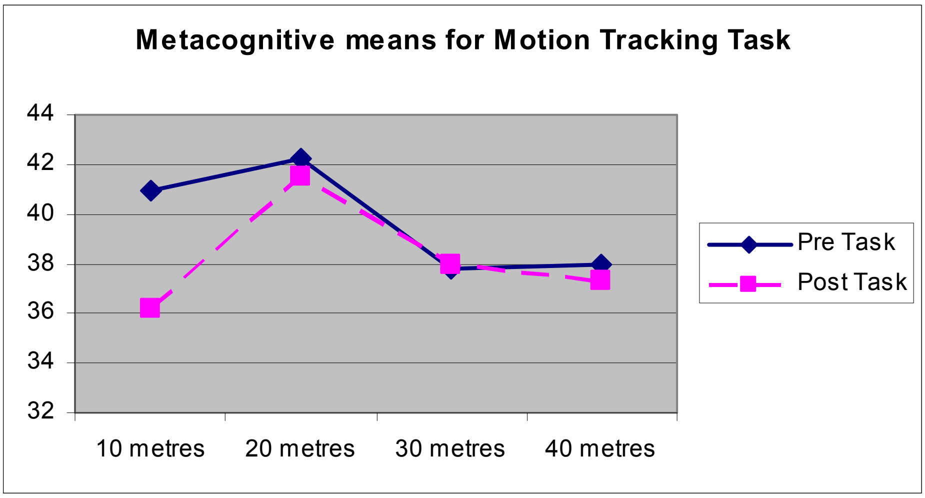


Chart 16: Word Pairs Pre Task -

	Surface Pre – 10 metres Pre	Surface Pre – 20 metres Pre	Surface Pre– 30 metres Pre	Surface Pre – 40 metres Pre
P-Value	0.791	0.532	0.544	0.831

Chart 17: Word Pairs Post Task -

	Surface Post – 10 metres Post	Surface Post – 20 metres Post	Surface Post – 30 metres Post	Surface Post – 40 metres Post
P-Value	0.968	0.398	0.650	0.026

Figure 9: Pre & Post Metacognitive means for Word Pairs Task

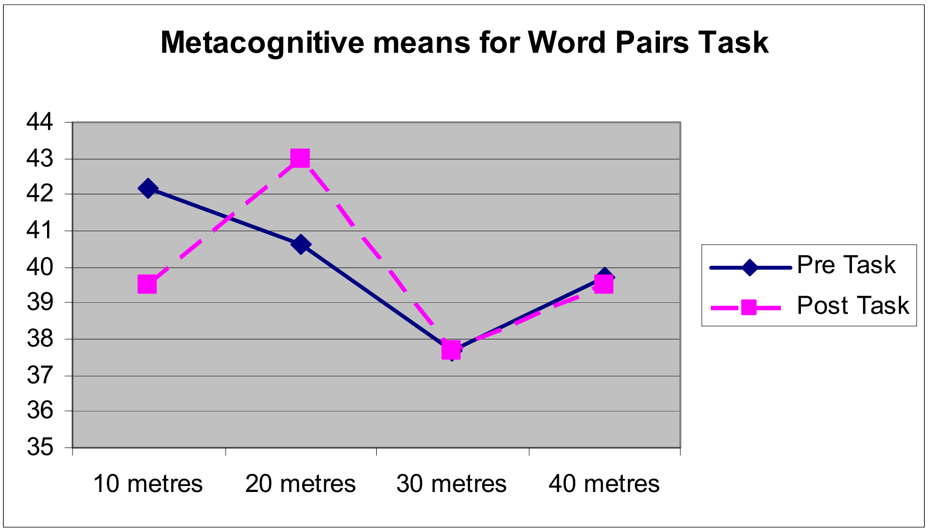


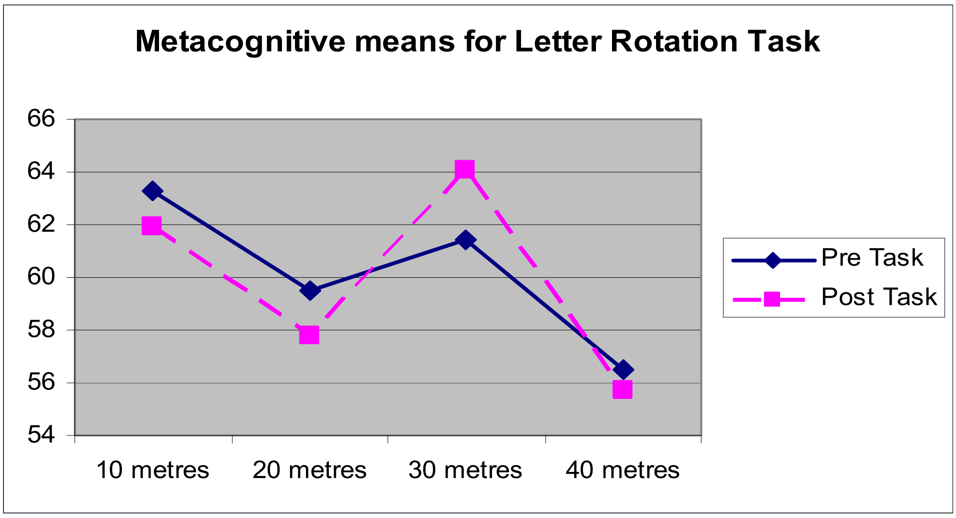
Chart 18: Letter Rotation Pre Task -

	Surface Pre – 10 metres Pre	Surface Pre – 20 metres Pre	Surface Pre– 30 metres Pre	Surface Pre – 40 metres Pre
P-Value	0.974	0.364	0.678	0.746

Chart 19: Letter Rotation Post Task -

	Surface Post – 10 metres Post	Surface Post – 20 metres Post	Surface Post – 30 metres Post	Surface Post – 40 metres Post
P-Value	0.113	0.574	0.499	0.069

Figure 10: Pre & Post Metacognitive means for Letter Rotation Task



6.5 ANALYSIS

Wilcoxon’s signed rank test is the non-parametric alternative to the repeated measures T-Test; and was utilised to compare data from the metacognitive judgements.

As reported above, there was a significant difference on the reaction time task between surface and 40 metres on the participants’ second trial day, but also that this difference disappeared when combining the 40 metres day one and two trials. Four significant results were found in the word pair task. Two differences lay in the number of correct responses given at 30 and 40 metres on the first trial day; the third was found between the surface and 40 metres on the first trial day, and the fourth occurs between the surface and 30 metres on the second trial day.

The metacognitive aspect of these results are more challenging to interpret and need to be considered in the context of the psychometric data.

At forty metres the participants believed that their performance would not be very good on the reaction time task. This presumption is borne out by the finding that there is a significant difference between the surface and this depth (but only on the second test day). However, after they had completed the task, the participants’ responses indicate that they did not believe that they had actually performed any more poorly than at the surface.

This pattern is reversed with the word pair task, where the participants believed that they would perform significantly better at 40 metres than on the surface. In this instance, the participants seem to have over-estimated their abilities, because although their responses at 40 metres (on the first trial day) and 30 metres (on the second trial) day were faster, the accuracy of their responses at these depths (on day one) was significantly impaired.

6.6 DEMOGRAPHIC ANALYSIS

Very little individual variation was detected in the performance of the participants either on the surface or at depth. No correlation was found between performance and any of the demographic variables.

This study attempted to balance its participant population to match the age and gender split of the United Kingdom's SCUBA diving population (reported in section 2.7). This was achieved by obtaining this information from the British Sub-Aqua Club (BSAC) and PADI (Professional Association of Diving Instructors) and recruiting the participants that fit into predetermined age and gender categories. This was done on a first come basis in order to avoid researcher selection of participants.

Other than the participants' age and gender, a number of other factors were recorded in the screening questionnaire. Sixty percent of the participant's classified themselves as recreational divers, with the remaining being commercial divers or a combination of the two. In this project 'commercial divers' we defined as anyone that earned money through their diving. This therefore included people such as SCUBA instructors and marine biologists, not purely those that work off shore although two of the participants did undertake saturation diving in their working life.

From information provided within the participant screening questionnaire it was calculated that only fifty percent of the participants had experienced narcosis prior to the chamber dive and these had an average subjective onset of 34.5 metres (Stdev = 9.14, minimum = 15 metres and maximum = 60 metres). This is a deeper than the researcher would have expected and may be due in part to inaccurate reporting, denial of the symptoms or lack of awareness of the symptoms.

There was also quite a variation in the number of dives performed by the participants in the last twelve months and over their entire diving career.

Chart 20:

	Mean	Stdev	Minimum	Maximum
Number of dives in the past 12 months	52	69.40	0	500
Number of dives in career	738.	1288.27	3	5000

A number of these demographic factors correlate (Chart 21). With the age being positive correlated with the number of dives you have performed during your diving career. Also as can been seen from the gender and experience data presented earlier, men have more career dives logged than women. It is also the case that those people that had dived a lot in the year prior to the trial had logged more dives over their entire diving career. Also recreational divers logged more dives than commercial divers and reported more experience of narcosis.

Chart 21:

		age	gender	diving 12 months	dive type	narcosis	narcosis onset	diving career
Age	Pearson Correlation	1	0.133	0.056	0.056	0.204	0.21	.363**
	Sig. (2-tailed)	.	0.199	0.605	0.605	0.52	1.88	0.001
	N	95	95	87	87	92	41	87
Gender	Pearson Correlation	0.133	1	0.187	0.058	0.091	0.188	.213*
	Sig. (2-tailed)	0.199	.	0.082	0.582	0.39	0.239	0.047
	N	95	95	87	92	92	41	87
diving 12 months	Pearson Correlation	0.056	0.187	1	0.172	.279**	-0.118	.337**
	Sig. (2-tailed)	0.605	0.082	.	0.112	0.009	0.474	0.002
	N	87	87	87	87	86	39	86
dive type	Pearson Correlation	0.056	0.058	0.172	1	0.062	0.141	.341**
	Sig. (2-tailed)	0.605	0.582	0.112	.	0.557	0.38	0.001
	N	87	92	87	92	91	41	87
Narcosis	Pearson Correlation	0.204	0.091	.279**	0.062	1	.a	.307**
	Sig. (2-tailed)	0.52	0.39	0.009	0.557	.	.	0.004
	N	92	92	86	91	92	41	86
Narcosis onset	Pearson Correlation	0.21	0.188	-0.118	0.141	.a	1	0.043
	Sig. (2-tailed)	1.88	0.239	0.474	0.38	.	.	0.795
	N	41	41	39	41	41	41	40
diving career	Pearson Correlation	.363**	.213*	.337**	.341**	.307**	0.043	1
	Sig. (2-tailed)	0.001	0.047	0.002	0.001	0.004	0.795	.
	N	87	87	86	87	86	40	87

**. Correlation is significant at the 0.01 level (2-tailed)

*. Correlation is significant at the 0.05 level (2-tailed).

a. Cannot be computed because at least one of the variables is constant

A linear regression analysis with this demographic data and the psychometric results revealed that none of the demographic variables predict the psychometric results.

7 Discussion

7.1 RESULTS OVERVIEW

The tasks employed in this study appear to measure performance at a stable level, and are not affected by learning or practice after two trial runs. Neither are they affected by exposure to breathing air under pressure. As pressure increased, however, participants gave less accurate predictions of how well they would perform the less cognitively demanding tasks. They were less confident of their ability to perform the reaction time task and the motion tracking task. The reverse is true for more cognitively difficult tasks (word pairs and letter rotation) here the participants' experience on the surface seems to have made the participants less confident in their abilities.

The interesting fact within these tasks is that although the participants' performance was no different at depth compared to on the surface, they did feel that they had performed better (although not significant on the letter rotation task) than they anticipated during the deeper dives.

These findings indicate narcosis is not simply an objective measurable phenomenon (Petri, 2003), but also that it has a significant subjective component (Section 4.5; Paragraph 4, section 4.6). That may well be explained by numerous interlacing factors such as experience, age, gender, motivation, heat, social psychology (sensation seeking and competition), as well as rate of descent, time of day, and the partial pressure of nitrogen, oxygen and carbon dioxide.

The main point to take away from this research is that it appears that on simple tasks, divers tend be more confident in their abilities at depth than at the surface. On more cognitively demanding tasks they do not have the same elevated level of confidence, but also do not report any decline in their perceived ability to do well on the task. Nor do they actually do worse at most of these tasks

It is also worthy of note that the demographic information collected from the participants did not help to explain the variation in the objective results obtained in this research. This would appear to indicate that experience does not have a significant impact on the reporting or experience of narcosis, or that the variation from day to day on such a diverse group of people is too great for this research. It is possible that these factors would have become significant if the sample size was considerably increased.

Why, if previous research using tests ostensibly measuring the same elements of cognition show an effect at depth (40 metres) and divers report an effect at forty metres (or at approximately 34m reported by this studies participants), did we not find the same thing? Some possible explanations for this are discussed below.

7.2 PARTICIPANTS

As we mentioned in the introduction, much of the work performed in this area of research has been performed on a participants that do not accurately represent today's recreational diving population. Fowler and Granger (1981) used 9 male and 3 female workers from DCIEM (Defence and Civil Institute of Environmental Medicine), Biersner (1987) used nine qualified divers and seven hyperbaric chamber observers from a submarine base, of which one was female and the rest (15) were male and Adolfson et al (1972) used ten Swedish Navy Divers in his research into standing steadiness. These are three random examples of studies with small sample sizes with groups of people that we could surmise to be 'fitter' and perhaps more 'adapted' than the average recreational diver. It would therefore be logical to say that they are not truly representative of the great majority of people SCUBA diving today, and therefore how can their results be applied to these people?

Also, there is a body of work in this field that utilises nitrous oxide as its narcotic agent and then generalises its results to the SCUBA diving field. Although this has been a popular methodology it has not been adequately demonstrated that this research is measuring the same pathology as that performed in a chamber or indeed whilst diving. The lack of clear aetiology of anaesthetics' function is the main reason for this research not fully embracing the findings of work done using nitrous oxide.

Other work has used hyperbaric chambers to simulate the pressures experienced during a 'dive', but even here there are potential problems with the methodology, some of which are discussed later in this section.

7.3 TASK EVALUATION

The research team believe that the use of computerised tasks is justified and valid in this project, however, it is acknowledged that there is some controversy surrounding the validity of computer administered cognitive function tests. Nevertheless they are accepted as a meaningful research tool for epidemiological studies in a number of field studies including Occupational Psychology (Baker et al., 1985; Goldburg et al., 1970). The test battery used for this study was chosen to provide a general screen of cognitive function rather than detailed examination of any particular aspect.

The reaction time task and the motion tracking task were designed to evaluate relatively low levels of cognitive functioning and it is therefore not surprising that there are no significant differences within these tasks between the surface measures and those at any of the simulated depths. This indicates that the level of narcosis experienced at these depths is not sufficient to cause a measurable decline in performance on these tasks, but it is possible that these would decline at greater depths. To assess this would be difficult in a hyperbaric environment due to the requirements to use more exotic mixed gases with a lower level of oxygen to prevent oxygen toxicity. The addition of other inert gases to replace the oxygen could have the effect of decreasing the level of narcosis and therefore negate performing the task. Another method would be to replace the oxygen with more nitrogen; this would of course increase the risk of decompression illness, as well as increasing the partial pressures of nitrogen and confounding the results. It has been argued (Dickson, Lambertsen & Cassils, 1971) that there is a need to obtain data over a complete range of narcosis from zero effect to complete loss of purposeful function before it will be possible to predict quantitatively the tolerance of man to high pressures of inert gases. However, it would appear more beneficial to today's divers to investigate the psychological impact of the gas mixtures being regularly used by recreational divers.

The study of memory and recall fall in a very active field of research. Like many aspects of physiology and psychology, memory is not very well understood, but there are a number of factors that need to be discussed about the task used in this research. Was this study looking at short or long term memory? According to Atkinson and Shiffrin, (1971) we can hold information in the short term memory for between 15 and 30 seconds, but this can be extended through rehearsal or repetition. As we did not allow for these two mechanisms to take place, and we had approximately 120 seconds between the presentation and the requirement for the participant to recall the word pairs, we can say that we were assessing long term memory in this research. It is debateable how the words transfer from short term memory to long term memory if there is not time for task repetition. In this situation the participants are shown the word pairs for four seconds and in this time have an opportunity to repeat the word pairs to themselves numerous times. This could act as a buffer between the sensory memory and the long term memory by maintaining incoming information within the short term memory and thus allowing transfer to the long term memory. One explanation for the retrieval phase of this task may be *confabulation*. This kind of memory error is often made under conditions of high motivation or arousal – if you are unable to recall a certain item, we may manufacture something that seems appropriate. For example, the detailed accounts that hypnotised people give of their childhood birthdays often turn out to be confabulations; they seem to combine several birthdays and 'fill in' the missing details. In this task the participants did not have a chance to give their own interpretation but were forced to decide on choices presented to them, but reported that some word pairs were always the same and seemed to be apparently paired, where this was not actually the case in the presented words. Another explanation of the participants recall could be *pattern recognition*, the sensory input triggers a match in the long term memory, which can then be verbalised or in this case reacted to. To understand the impact of narcosis on memory would require a specific research project, in this study it was sufficient to note that this complex level of functioning is indeed disrupted during exposure to elevated atmospheric pressures, although there may be a speed accuracy trade off occurring with the participants feeling that it is better to respond quickly than to ensure an accurate response. This may be due to an elevated level of motivation, or that SCUBA divers are high sensation seekers (Zuckerman, 1994; Harding 2002) that are more aroused by responding than by the ensuring the response is accurate.

The letter rotation task has its roots in pattern recognition. Pattern recognition is the central problem of perception and is almost synonymous with perception itself – how are we able to recognise, identify and categorise objects? What are the processes by which sensory information is converted into a psychologically meaningful perception? Eysenck (1984) defined pattern recognition as *'assigning meaning to visual input by identifying the objects in the visual field'* and believed that the ease with which we normally succeed in identifying objects in fact conceals the, *'amazing flexibility of the human perception system as it copes with a multitude of different stimuli'*, a remarkable achievement. By far the most researched and influential theory of pattern recognition is that of 'Feature Detection Theory'. This maintains that each stimulus pattern can be thought of as a configuration of elementary features. Letters of the alphabet, are composed of a combination of about twelve basic features (including straight vertical lines, horizontals and closed curves) so an 'A' may be analysed into two diagonals, one horizontal, a pointed head and an open bottom. It was therefore important in this task to chosen the appropriate letter for the investigation. The letter 'R' was selected, due to its non-symmetrical nature when flipped and/or rotated, and it's composition of curves which required a high level of attention to discriminate between a normally view R and a flipped Я.

Computerised cognitive tests are often employed in these situations as they overcome many limitations associated with the administration of paper and pencil neuropsychological tasks at brief intervals. For example, stimulus presentation and contingency onset are controlled by the software (thereby reducing any inter- or intra- assessor unreliability), and data collection and analysis may be automated. In addition, automated cognitive tasks often have brief administration times yet still provide reliable data for comparisons of performance between experimental situations or baseline conditions within individuals, as in this case. Despite the widespread use and acceptance of computerised tasks, there remains little published data describing the effects of practice at these brief test-retest intervals. Even taking this lack of data into account it seems that the deficits faced when using this type of methodology are out weighed by benefits of standardised task presentation and data collection.

The use of computers in research is becoming more accepted for a number of reasons; one being that they are being used more and therefore if research is to progress the methodology has to be assessed and accepted; and also more people use computers in their day to day life and are therefore comfortable with how they present stimuli and how they respond to it. This familiarity could help explain the lack of narcotic effect found in this research, as the participants could have found the tasks easier than their experimental predecessors simply due to their confidence with computers.

As with all forms of cognitive deficit there can be many negative repercussions in how the person can and does perform. As with alcohol, it has often been cited that narcosis has specific manifestations (Bennett, P. B. 1997), from laughter, loquacity and light headedness and fixation to slowed reaction times at extreme depths. It is therefore important for divers to be aware that their performance may be affected and the ability to assign a number makes the affects more concrete. It is clear from this research however that it may not be possible to assign a number to the depth of onset of narcosis. This is due to its clear variation between individuals and the likelihood that experience, age, gender fitness and indeed adaptation and experience of the environment may affect this onset of narcosis or the ability to adapt to it.

7.4 CONFOUNDING VARIABLES

There were variables present in this research which the team attempted to control for. These include gas partial pressures, temperature, rate of compression, type, age, training of divers, practice but not, for example, the possible effects of motivation.

One factor that is very difficult if not impossible to remove from a study is that the participants were aware they were being ‘tested’. The participants knew that they were attending DDRC to undergo a chamber dive and whilst doing so to perform tasks to evaluate changes in there performance. It could be argued that they were *attending* (focusing) to the task in a ‘work’ like fashion and this focus could have counteracted the effects of narcosis. Would it be possible to test the participants in a naive way, or make the situation less work like and more similar to SCUBA diving?

It is commonly believed that there is marked individual variation in susceptibility to inert gas narcosis but all divers breathing compressed air are significantly affected at a depth of 60-70 metres. As this research shows, the minimum pressure producing signs is difficult to define.

Adolfson, (1964, 1965) & Muren (1965) noted that there was a rapid acclimatisation to the effects of depth. However the symptoms were much more similar to psychedelic drugs, rather than alcohol, which is customary analogy to narcosis.

It is, however, possible to be exposed to such pressures or even deeper without undue narcosis, provided that the compression is rapid and the exposure brief. Normally rapid compression potentates compressed air narcosis (Adolfson 1964; Albano 1962, 1970; Bean 1950; Bennett 1965a, Shilling & Willgrube 1937), but if insufficient time is spent at depth to permit the critical concentration of nitrogen necessary for narcosis to accumulate in the brain, narcosis does not occur. This, however, goes against the research that finds narcosis being subjectively worse on arrival at depth; especially if the depth is reach quickly (Lippmann, 1996)

It has long been supposed that the rate of compression has an effect on the degree of narcosis (Lippmann, 1996). For this reason, the rate of compression is carefully controlled during experiments. It is an unfortunate fact that many researchers have not published the rate of compression that they used in their research. Sparrow et al (2000) is one of the few exceptions to this and, as with this study, used a rate of 10 metres a minute (1 ATA/ 1 min). They however, performed their control trials at 1.5 ATA explaining that this allowed for the elimination of external cues and therefore the participants ability to evaluate the true pressure and were therefore blinded to pressure. To test the participants ability to perceive the pressure Sparrow et al, interviewed them after the experiment and in no case could they identify the test pressure. This was done on an informal basis in this research and it was noted by the researcher that the majority of participants could not identify the test depth on the initial test, but on the second test depth were able to say if they had been deeper or shallower than their previous dive. It is also worthy of note that participants that had experienced dry chamber dives previously, guessed their test depths with a great deal of accuracy.

7.5 ENVIRONMENTAL FACTORS

As noted earlier, Sparrow et al (2000) used a false compression in order to control for environmental blinding. They reported an adjustment in valve configuration to allow for increased sound and temperature level, although they do not inform us as to the procedure used to make the temperature rise equivalent to that experienced at test depths (4 ATA).

Although there are numerous ways to control for the environmental factors experienced in dry-chamber research, it still does not easily equate to the experiences in either an open water environment or indeed a wet-chamber.

One of the issues raised by Sparrow et al (2000) is the practice of using 1.5 ATA as a control group. It can be argued that the onset of narcosis occurred in the same manner as drugs (in a dose-response curve) and therefore even at 1.5 ATA there could be an affect of narcosis. It would surely be better to simulate a dive with the addition of sound and heat without increasing the atmospheric pressure? If this research team were to perform this project again they would use this method during the surface trial runs of the task (Mills & Harding, 2004).

One of the major environmental factors that differs from in-water SCUBA diving and that performed in hyperbaric chambers is that of temperature changes. In the water the body loses heat quite rapidly through conduction and even in warm water, divers can become hypothermic. In a chamber environment after even a slow compression (1 metre a minute) the temperature can easily raise five to six degrees Celsius. During this research it was noted that the average temperature within the chamber at 1ATA was twenty three degrees Celsius and increased an average of five degrees during compression to ten metres and a further two degrees for every 10 meter increase in depth. Physiologically, any factors that influence the central integration of thermal afferent information may also influence behavioural responses. Epstein, Keren, Moisseiev, Oded and Yachin (1980), reported that speed of performance was significantly higher when participants were exposed to moderate heat (30°C) rather than to high (35°C) or comfortable heat (21°C). They came to the conclusion that a) the effect of the intensity of the task and heat load on deteriorating performance are synergistic; b) psychomotor performance deteriorates even before physiological parameters are impaired, possibly due to feelings of discomfort; c) even highly motivated participants are effected by heat load, especially when assigned to complex tasks which require a high state of functioning. This finding, combined with Mekjavic et al (1995) who stated that narcosis induced by hyperbaric exposure affects numerous central nervous system functions and also impairs thermal perception, could partly explain the lack of significant differences in this research and also the apparent tendency for some individuals to improve at the task whilst at depth.

Mekjavic's experiments conducted with humans revealed that subanaesthetic levels of inert gas narcosis increase thermal comfort during mild hypothermia, and divers perceive their body temperature to be higher than when in identical conditions but without narcosis. The conclusions of these studies support those of Pertwee et al (1986, 1990), who exposed mice to a range of subanaesthetic levels of N2O and hyperbaric N2. Given the choice of a cold or warm environment during exposure to mild narcosis, the mice chose the cold environment. This clearly adds further support to the assertion that the increased temperature within a compressed chamber would have significant confounding effects on research attempting to measure narcosis and the participants perception of their performance whilst in that environment. The thermo neutral zone is elevated and significantly narrowed in hyperbaric environments; thermal comfort requires ambient temperatures of approximately 30°C in dry atmospheres at depths greater than 100 msw (328 fsw), (Wilcock & Flook 1980). This is several degrees Celsius higher than the temperature required for thermal comfort at 100 KPa (1.0ATA) (Nishi & Gagge, 1977)

It has often been noted at DDRC during its routine elective therapies and emergency therapies that the level of carbon dioxide elevates significantly during compression. This same factor was noted during the compression stage of this research (Chart 22).

Chart 22: Carbon Dioxide Levels in Chamber (mbar)

	Minimum	Maximum	Mean
Surface	0.3	3.1	0.5
10 meters	1.4	4.8	2.8
20 meters	1.8	4.5	2.9
30 meters	2.2	5.1	3.5
40 meters	2.7	5.8	4.3

Obviously elevated partial pressures of carbon dioxide are not desirable and therefore we utilised a 'scrubber' (a cylindrical canister with perforations encompassing its length, toped with a silicon seal and filled with a carbon dioxide absorbent crystal, this is placed on top of a fan which cause the chamber air to circulate through the crystals and in doing so remove the carbon dioxide). The use of the scrubber explains the large variation between the maximum and minimum figures presented in chart 22 (above). Behnke (1945) and Lanphier (1981) have noted that there can be a magnification of narcosis when significant elevations of carbon dioxide coincide with exposure to a narcotic or near-narcotic partial pressure of inert gas. Experiments by Rashbass (1955) and Cabarrou (1959, 1964, 1966), in which measurements of alveolar carbon dioxide were compared with quantitative measurements of narcosis, failed to support the carbon dioxide theory, except in regard to its synergistic properties. That respiratory embarrassment does occur at increased pressure is not disputed. Indeed, there is ample evidence in support of this (Lanphier 1963; Miles 1957; Wood 1963; Wood et al 1962). However, causes of altered consciousness in diving were the subject of an Undersea Medical Society Workshop (Lanphier, 1981), and carbon dioxide retention and other abnormalities of respiratory control were ranked among important causes of impairment.

It may be predicted, owing to increased synergistic carbon dioxide retention as a result of the breathing equipment and work of swimming that the narcosis would be more severe in actual ocean diving as compared with simulated dry pressure chamber exposure (Baddeley 1966, Davis et al 1972)

It may also be possible to account for some of the environmental influences on behaviour by constructing indexes from research on factors such as noise (Eschenbrenner, 1971) etc.

7.6 ADAPTATION

In section three of this report, it was noted that a greater number of participants performed their shallow (10 or 20 metres) dives before their deep (30 or 40 metres) ones. This could have the effect of acclimation to chamber dives and therefore reduce the incidence of narcosis that may have been experienced if a chamber dive was still novel.

Lippmann (1996) tells us that *'diving requires that we learn to adapt to the physical, sensory, physiological and psychological changes, however we are unable to adapt completely, only partially, and as divers we must learn to allow for changes. Most of the problems and changes are inherent to all dives but some problems are magnified, and some new problems arise, as the depth of diving increases.'* The question that arises from this is, is it possible to adapt to narcosis?

As discussed earlier, we know from psychological literature investigating perception, that the human nervous system is very flexible in its ability to overcome distortions forced upon it by external factors. Croussore & Grube, (1975) have shown that adaptation takes place on three systems: visual, motor, and proprioceptive, and that this can occur very rapidly. O'Reilly and Ono (1971) used eighteen experienced divers and found that the participants' performance benefited from adaptation time. This has two implications, the first is that narcosis is worst on arrival at depth, and secondly that by remaining in the environment you will eventually adapt to it, but that it is possible that adaptation is required anew every dive.

Moeller and Chattin (1975) suggested that their findings indicated that situation-specific experience of 'narcosis', as opposed to general experience in hyperbaric contexts, has been seriously underestimated in practice and in studies of the depth-performance relationship. They suggest that there is a carry over effect from simply experiencing a dry dive of any depth to the performance in subsequent chamber dives. This finding may help explain the results in this work, as more participants performed their shallow dives prior to their deep ones.

Another possibility is that training decreases inattention to the task as a result of the variety of subjective sensations associated with narcosis (Fowler and Ackles, 1972; Frankenhaeuser, 1963). Therefore, simple familiarisation with the diving environment may allow for a greater consideration for the problem/task at hand. Therefore the more experienced a diver is in a given diving situation, the better they might perform at a task. This would support the hypothesis that experienced divers suffer less from the symptoms of narcosis, but that there is still variation between dives, as each dive will have a different level of visibility, will be a different temperature and the diver will be motivated to varying degrees to attend to the tasks in hand. It is perhaps a factor in this study that by simply having the participants perform the tasks may have provide sufficient focus and motivation for a reduction in the levels of narcosis experienced and reported.

According to Berlyne (1967), exploring the unfamiliar increases arousal. However, if the unfamiliar is too different from what we are used to, arousal will be too high (you would feel anxious and tense) while if it is not different enough, arousal is too low (you soon become bored). Our optimum level of arousal is partly determined by how relaxed we are feeling initially: when we are relaxed we are more likely to welcome novel and challenging experiences (to increase arousal) whereas when we are already tense, we prefer to deal with what is already familiar and relatively undemanding. This simple account of motivation offers a very clear rational for the occurrence of adaptation to narcosis or at least the ability to cope with the hyperbaric environment. In future work techniques would be adopted to minimise (eliminate) or quantify arousal and vigilance.

It is important for diver safety and education if the adaptation noted is subjective but behaviour effects are not changed.

7.7 FUTURE RESEARCH

Several factors were identified in this report as being possible confounding variables or worthy of note in future research. Some of these factors may even deserve investigation as a primary factor.

The rate of compression is anecdotally responsible for narcosis, or at least for the severity of the experience. In this study the compression rate was standardised to remove this factor and to ensure that the maximum number of people could make it to depth without suffering from barotraumas. It would be possible to perform the study on a smaller number of people using varying compression rates.

The nature of narcosis suggests that it is the changes in partial pressures of the inhaled gases that change behaviour. It would therefore be beneficial to consider possible control groups available in a hyperbaric environment. A suggestion would be to use a surface (1 ATA) trial run or a sham dive (1 ATA with noise and warmed air pumped through the chamber). On other hyperbaric studies it would be desirable to control for the partial pressures of the breathing gases. In this study it would not be sensible to use a surface equivalent partial pressure of air at depth, due to the drop in oxygen and the need to replace the difference with a gas that would not change the effect of nitrogen, such as Neon or Argon.

Further work is also possible in the field of hysteresis and adaptation. Are the effects of narcosis greater on arriving at depth, then subsiding if depth is maintained and are these effects lessened if similar dives are performed? Is it possible to acclimate ('dive up') to a specific dive?

An avenue of study that has yet to be sufficiently explored in that of ‘mixed gas’ diving. This is becoming more popular and accessible to SCUBA divers and a comparative study with individuals diving on air and then on various partial pressures of oxygen, nitrogen and inert gases such as helium (most commonly used in tri-mix).

It has been suggested by Sparrow et al (2000) that a change in strategy of problem solving during memory recognition tests occurred and that speed tests showed a progressive error rate under pressure with time. Petri (2003) did not find a progressive increase in the number of errors or constant working speed. It would therefore suggest that future working investigating strategy change during narcosis would be beneficial to our understanding of this phenomenon.

As mentioned by Zuckerman (1994) and Harding (2002) there are personality factors that may have an impact on the coping and ‘adapting’ to the environment. These could be such facets as sensation seeking & risk taking, as well as more traditionally identified factors as extraversion, arousal and motivation.

As noted in the confounding factors section (4.4) of the discussion, the participants being aware that they were being tested could have made the participants concentrate more than if they were in a SCUBA diving situation. These ‘work-like’ tasks represent a good means of looking at the effects of narcosis but may be more affective in examining the fitness to perform in other conditions of work, such as saturation diving.

SCUBA diving can be a very social activity involving ‘buddies’ and ‘dive clubs’; it may therefore be more effective to measure narcosis in situations with larger groups of people in a ‘social environment’ such as a chamber dive.

8 Conclusions

Participants are confident in their abilities to perform light cognitive tasks, but question how well they have done once the task has been performed. The reverse is true for cognitively demanding tasks, where they are not confident, but then report that they believe they did well.

The study indicates narcosis is not simply an objective measurable phenomenon; it also has a subjective facet.

The demographic information collected from the participants did not explain the variation in the objective results obtained in this research. This indicates that experience does not have an impact on the reporting or experience of narcosis, or that the variation from day to day on such a diverse group of people is too great for this research. It is possible that these factors would have become significant if the sample size was considerably increased.

This study identifies the large variation within divers and the complex environment encountered in the hyperbaric environment. The report identifies the possibility that the process of testing may have been sufficient to change the tasks from mere measures of performance to ‘work-like’ tests therefore focusing the participants more than in a SCUBA situation.

The pattern of changes seen in the research suggests that further study into metacognitive impact of increased atmospheric pressures is needed, and that greater focus needs to be placed on individual psychology, especially in the fields of motivation, sensation seeking and adaptation.

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APPENDIX 1: PARTICIPANT INFORMATION SHEET

Participant Information Sheet – May 2002

Investigating the relationship between simulated depth, cognitive function and metacognitive awareness.

You have been invited to participate in a study that is investigating the effects of simulated depth, cognitive function and your awareness of your cognitive function.
Cognitive function can be thought of as how you think. Awareness of cognitive function is how well or accurately you believe you are thinking. For example; when you have been drinking alcohol you are aware that you need to concentrate more to do relatively simply things.

If you volunteer to participate in this study we will ask you to complete a questionnaire recording your diving experience and other aspects of your dive history.
If you have any medical condition, are taking, or have recently been taking medication you must let DDRC know and not participate until cleared to do so by one of the DDRC doctors.

As a volunteer you would be expected to participate in at least two hyperbaric chamber dives (to a maximum depth of 40 metres) and perform a series of tasks while at depth. You will not be informed of the depth to which you dive until you have completed your participation in the study. You will also be required to complete the tasks while in non-pressurised chambers.

The chamber will be compressed using air. It is therefore possible that during some of the dives you may experience the effects of Nitrogen Narcosis. This is due to the high partial pressure of Nitrogen. This affects different people at different depths and the chamber attendant will be monitoring you to ensure that the level of narcosis does not become such that you can not safely complete the dive.

A trained DDRC chamber attendant will be in the chamber with you throughout the dive. A DDRC operator and/or Supervisor will operate the chamber. The chamber will not be compressed unless there is a member of the medical team on site.

Possible risks involved

- Decompression Illness: DDRC has constructed the dive profile (using DCIEM tables, the Canadian Defence tables based on no bubble formation) to be very conservative to minimise the likelihood of this occurring. DDRC also insists that participants remain on site for at least an hour after surfacing from a chamber dive as part of a 'bends watch'.

- Aural & Sinus Barotrauma: The chamber attendant will instruct you on a number of ear clearing methods but it is your responsibility to tell the DDRC staff if you have any disorders (e.g. head colds) that may limit your ability to clear your ears on a rapid descent. We would rather you did not suffer any pain while diving. If you do feel any discomfort raise your hand and say "STOP" so the chamber attendant can address the problem.

- Pulmonary Barotrauma: This is caused by trapped air in the lungs (due to an asthmatic attack for instance or breath holding). If you have any upper respiratory tract infections then you should not be diving. You should also inform the DDRC staff as to any respiratory disorders you may have suffered from in at least the last month. This could lead to conditions such as Pneumothorax or Arterial Gas Embolism.

    - Pneumothorax: If the lung ruptures due to a pulmonary barotrauma this it becomes a Pneumothorax. As above you should not dive with a cold or inform the DDRC staff if you have had one in the last month.

    - Arterial Gas Embolism: If gas trapping occurs the emboli may pass through the alveolar walls into the surrounding tissues and into the blood stream. To prevent this, is it important not to dive with an upper respiratory tract infection. Also if you experience any discomfort on the descent you must inform the chamber attendant.

- Nitrogen Narcosis: If the chamber attendant feels it is inappropriate for you to continue due to narcosis, the chamber will be surfaced following the decompression schedule.

- Fire: Only clean cotton clothes should be worn in the chamber. If you do not have any such clothing, DDRC can supply you with some. Footwear must be removed or covered prior to entering the chamber and no items on the forbidden items list (displayed at the chamber entrance) can be taken into the chamber.

- Oxygen Toxicity: For some of your dives you will be asked to ‘go on oxygen’ at three metres. This is an added safety precaution used at DDRC to reduce the risk for decompression illness. It is worth noting that there is a risk of Oxygen Toxicity but this is very rare, resulting in epileptic style convulsions. This is easily dealt with by removing the source of oxygen.

Please ensure that you:

- Refrain from drinking alcohol for at least 18 hours prior to the chamber dive
- Are well hydrated before arriving at DDRC

- Have not had a hyperbaric (diving) experience for at least 18 hours prior to the trial (chamber) dive.

- Have a formal certificate of fitness to dive. Either a sport diving self-certification or HSE commercial diving medical certificate. These will be reviewed by the DDRC medical team

- Have completed a DDRC Health Questionnaire.

- Have brought your Diving logbook.

- Do not fly for 72 hours after the completion of the chamber dive

You are welcome to bring your dive computers and a bucket of water will be supplied for these to be put in. DDRC does not accept responsibility for any damage to such items.

We expect the total time for each visit to last approximately 3 hours. This includes a compulsory one-hour ‘bends watch’.

Before commencing the study, Ms Sam Harding will explain more fully what you need to do and will answer any questions that you may have.

The data generated in this study will be looked at as a group and your results will not be compared against any other individual.

We have a very strict code of confidentiality by which we can guarantee you that:

- Your confidentiality is assured. For the purpose of recording and analysing the results we will anonymise the data.
- When responding to the questionnaire and tasks, there is no right or wrong answer, so it is important that you respond in the way you feel most fits your situation.

APPENDIX 2: CONSENT FORM

Consent Form

Investigating the relationship between simulated depth, cognitive function and metacognitive awareness.

I have read the description of the study on the previous pages and I understand that I will be asked to complete a series of questionnaires and computer based tasks and I agree to participate.

I have truthfully completed the DDRC Health questionnaire and to the best of my knowledge am medically fit to participate in this trial.

I understand that I can quit the study at any time and this will not have any repercussions on any other treatments I maybe having and that my participation and the record of my response will be kept in the strictest confidence.

Patients Name (In Capitals)___________________________________

Participant Signature: *Date:*

Consent Obtained by: *Date:*

If you have any questions regarding this study please feel free to contact:

Sam Harding

DDRC, Hyperbaric Medical Centre,

Tamar Science Park,

Research Way,

Plymouth. PL6 8BU

☎ *01752 209999*

sam.harding@ddrc.org

Full ethics approval for the study has been obtained from the local Independent Ethics Committee. If you have any questions about your rights as a research volunteer you may contact the chairman, Dr David Keeling, on 01822 852305.

APPENDIX 3: SCREENING QUESTIONNIARE

Investigating the relationship between simulated depth, cognitive function and metacognitive awareness.

SELECTION QUESTIONNAIRE:

In order to make the research as applicable to the general diving population DDRC is attempting to stratify their participants to match as closely as possible the national statistics for divers.

Please complete this questionnaire and send it back to Sam Harding at DDRC (sam.harding@ddrc.org).

GENERAL INFORMATION:

1. Name (in Capital Letters)____
2. Address ____
____
____
____
____
3. E-mail Address____
4. Day Time Telephone Number ____
5. Evening Telephone Number ____
6. Date of Birth __/__/____ (dd/mm/yyyy)
7. Age ________

8. Male ☐ Female ☐

9. What educational qualifications do you currently have?
(Please indicate the number of each type of qualification that you have by putting a number in each set of brackets e.g. **CSE [5]**).

A-Level ☐
BTEC ☐
CSE ☐
GCSE ☐

Graduate ☐
HNC ☐
HND ☐
O-Level ☐

ONC ☐
Postgraduate ☐
Undergraduate ☐
Others ☐

10. What is your current job title? ____________________________________

DIVING HISTORY:

11. Through which organisation/s are you currently qualified? ***(please circle)***

BSAC
CMAS
IANTD

NAUI
PADI
SSI

TDI
SAA
HSE

Military
None
Other

12. With which organisation did you do most of your training? ***(please circle)***

BSAC
CMAS
IANTD

NAUI
PADI
SSI

TDI
SAA
HSE

Military
None
Other

13. What is your highest diving qualification?___________________________

14. What other diving related qualifications do you hold? (e.g., PADI wreck diver)

____

15. With which organisation is your highest qualification? ________________

16. Are you a regular member of a dive club?

No ☐ Yes ☐

If *yes*, which club or institution? _______________________________

17. In what year did you learn to dive? _______________________________

18. How many dives did you do in the last twelve months? _______________

19. How many dives in total have you done since you started diving?

Saturation (days) ☐ Surface Supply ☐ SCUBA ☐

20. When was your most recent dive? (*not today)*___/___/_____(dd/mm/yyyy)

DIVING EXPERIENCE:

21. Do you mainly dive in cold (below 20°C) or warm (above 20°C) water, or a mixture?

22. Approximately how many dives have you done? (not including saturation dives);

Up to 18m ____

Between 19m and 30m ____

Between 31m and 49m ____

Between 50m and 74m ____

Between 75m and 99m ____

Between 100m and 124m____

Other____

23. For each depth range what gas mixtures would you have been breathing? (not including travel or decompression gases);

Up to 18m ____

Between 19m and 30m ____

Between 31m and 49m ____

Between 50m and 74m ____

Between 75m and 99m ____

Between 100m and 124m____

Other ____

DIVING PRACTICE:

24a. What type of diving are you usually involved in?

Leisure/Sport ☐ Professional ☐

24b. If **Professional**, which of these jobs do you do (*tick as many as is appropriate*)

- Search & Recovery ☐
- Welding ☐
- NDT ☐
- Oilfield Maintenance ☐
- Civil Engineering ☐
- Inspection ☐

25. How do you plan your dives?

Computer ☐ Table ☐ Both ☐ Other (specify)………………

26. Have you experienced Inert Gas Narcosis?

No ☐ Yes ☐

If yes, what depth do you first notice the effects? ___________ metres

What gas where you breathing? ___________________ %O_2 __________

What signs and symptoms did you have? __________________________

27. Have you ever had a Barotrauma brought on by diving?

No ☐ Yes ☐

28. Do you knowingly do slow ascents to prevent barotrauma?

No ☐ Yes ☐

29. Have you ever been positively diagnosed ***by a medical practitioner*** as having decompression sickness?

No ☐ Yes ☐

If *yes*, please give details

Year____

Maximum depth of dive in question ____________________________

Outside table/computer limits No ☐ Yes ☐

Please give any further information that you feel may be pertinent.

____

____

____

30. In your opinion have you suffered mild decompression illness, **not diagnosed by a medical practitioner**?

No ☐ Yes ☐

If *yes*, please give details

Year____

Maximum depth of dive in question ____________________________

Outside table/computer limits No ☐ Yes ☐

Please give any further information that you feel may be pertinent.

____

____

____

31. Have you suffered mild decompression illness, which was treated with normobaric (surface) Oxygen?

No ☐ Yes ☐

If *yes*, please give details

Diagnosed by a Medical practitioner No ☐ Yes ☐
Year____
Maximum depth of dive in question ____________________________
Outside table/computer limits No ☐ Yes ☐

Please give any further information that you feel may be pertinent.

____

____

____

APPENDIX 4: TASK BRIEF

Instructions to boot-up computer:

1. Set up Chamber 3 as specified in Chamber Three Checklist (SOP DP**).
2. To power up 'Trial' Screens (in the chamber) ensure the button labelled 'Computer' is turned on in the power supply cabinet.
3. Turn on 'Trial Computers'.
4. Ensure the trials 'Mice' are functioning adequately.
5. Load the programme 'Test Battery'. This can be found as a short cut on the desktop of the computer.
6. Select participant number from the drop down list. The participant number can be found in the research file held in the nursing office.
7. Click screen button 'Load Tasks'.
8. Click screen button 'Start Tasks' when ready to begin testing.

Task abbreviations:

RT	simple reaction time task
LR	Letter rotation task
MT	Motion Tracking
WP	Word Pair memory task

9. If you need to interrupt testing during the trial hold down left control and escape to exit.

Participant Instructions:

Thank you for agreeing to participate today. This study is interested in the effects of simulated depth on both cognitive performance, and self-perceptions of performance. In this study, you will be presented with four different tasks. Before each task you will be asked to predict how well you are going to do, and after each task you will be asked to say how well you did. The four tasks are

1: A simple reaction time task (RT), in which you have to press a button as quickly as possible whenever a target appears.

2: A letter rotation task (LR), in which you have to judge whether two letter shapes can be rotated so as to match each other.

3: A motion tracking task (MT) in which you have to try to keep a dot within a moving target on the screen.

4: A word-pair memory task (WP), in which you will be presented with pairs of words, and your task is to remember which word was paired with which. These two phases (study and test) will be separated in time.

You will have to complete this set of tasks on several occasions, and each time, the order will change.

Do you have any questions about what you have to do?

As an example, I will go through one possible presentation order with you and explain what you need to do to complete each task.

The order we will look at is:

WP-MT-WP-RT-LR

When the chamber attendant (the DDRC member of staff in the chamber with you) tells you to, click on ‘Start Tasks’.

Task 1: Study phase of the word-pair task.

For this task you are asked to try and remember a set of word-pairs. You will see 40 pairs of words on the screen, for just under 4 seconds per pair.

e.g.

COMPUTER SKY

ONION LAND

TRADE METER

etc.

Later, you will be asked to remember these pairs. You will be shown word pairs and will be asked if the words are correctly paired up. i.e. in the recognition test all the words will have been seen before, but they may not be in the same pairing.

Click the mouse to start the task.

Word-pairs will then be shown on the screen. You do not have to do anything except try to remember the word-pairs.

At the end of the word-pair presentations, we will automatically move on to the next task.

Do you have any questions about this task?

Task 2: The Motion Tracking task.

For this task you are asked to keep the small inner circle inside the larger target circle. This target will move randomly round the screen for 2 minutes. At the start of the test the circle will be 25mm wide, but it will decrease to 10mm wide by the end. Before you complete the task, you will be asked to rate how well you think you will do at the task:

You can move the mouse to indicate how well you think you will do on this task. Once you have moved the arrow to the point of the scale that corresponds to how well you think you will do on the task, click the mouse button.

Once you have made your rating, the screen will change and when you are ready to begin, please click on the mouse.

Using the mouse try and keep the small inner circle inside the larger circle.

At the end of the tracking task you will be asked to indicate how well you think you DID on the task.

As before, you can move the mouse to the point on the scale corresponding to how well you did, again clicking the mouse button when you are happy with the rating.

Do you have any questions about this task?

Task 3: The test phase for the word-pairs.

In this task you will be presented with 40 word-pairs as before. ALL these words will have been presented earlier, but not necessarily in the same pairing. Your task is to decide, **as quickly as possible**, whether the pair of words you are presented with appeared earlier as a pair, or whether they were in different pairs. The computer will record your decision, and the speed with which you make the decision.

If they were previously presented together as a pair, LEFT click the mouse

If they did not previously appear together as a pair, RIGHT click the mouse.

For example, if we saw the word pairs above, the test phase might include:

COMPUTER SKY

This is the SAME pair as before, and so you should press the LEFT button.

ONION METER

This pair is DIFFERENT, and so you should press the RIGHT button.

Before you begin this task, you will be asked to indicate how well you think you will do on this task using the same scale as previously.

Once you have made judgements about all the word pairs, you will be asked to indicate how well you think you did on the task, again using the same scale.

Do you have any questions about this task?

Task 4: The reaction time task

For this task, you have to click the mouse button as quickly as possible whenever the target (a white spot) appears. There will be 60 trials, which should take around 7 minutes.

Before you begin, you will be asked to rate how well you think you will do on the task, using the same rating scale as before.

Once you have made your rating, click the mouse when you are ready to start.

You will then have 60 trials of the reaction time task. The spot will appear randomly around the screen, and your task is simply to click the mouse as quickly as possible whenever it appears. The computer will record the speed of your response.

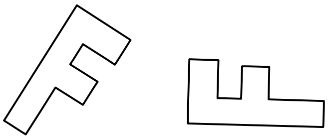
Once you have completed 60 trials of the reaction time task, you will be asked to rate how well you think you did on the task, using the same scale as before.

Do you have any questions about this task?

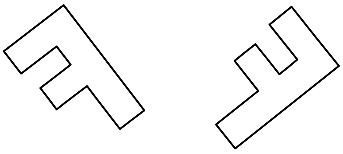
The letter rotation task.

In this task you will see pairs of letters, each of which is rotated from it’s standard upright position. Each letter will either be in its normal form, or a mirror image. Your task is to judge whether the two letters are the same, ignoring the rotation.

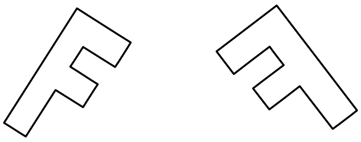
So, for example, the following pair is the SAME:



This pair is also the SAME, since both are mirror versions of the letter F.



The following pair are DIFFERENT, since one is a normal F, and the other is a mirror image. You could not rotate one, so that it matched up with the other.



In this task, you will see 62 pairs, and for each you have to decide, as quickly and as accurately as possible, whether they are the same, or different. The computer will record both the speed and the accuracy of your judgments.

If the pair is the SAME, click the LEFT mouse button.
If the pair are DIFFERENT, click the RIGHT mouse button.

Before you start this task, you will be asked to predict how well you will do on this task, using the same scale as before.

Click the mouse to start the task.

At the end of the letter rotation task you will be asked to rate how well you did on the task, using the same scale as before.

Do you have any questions about this task?

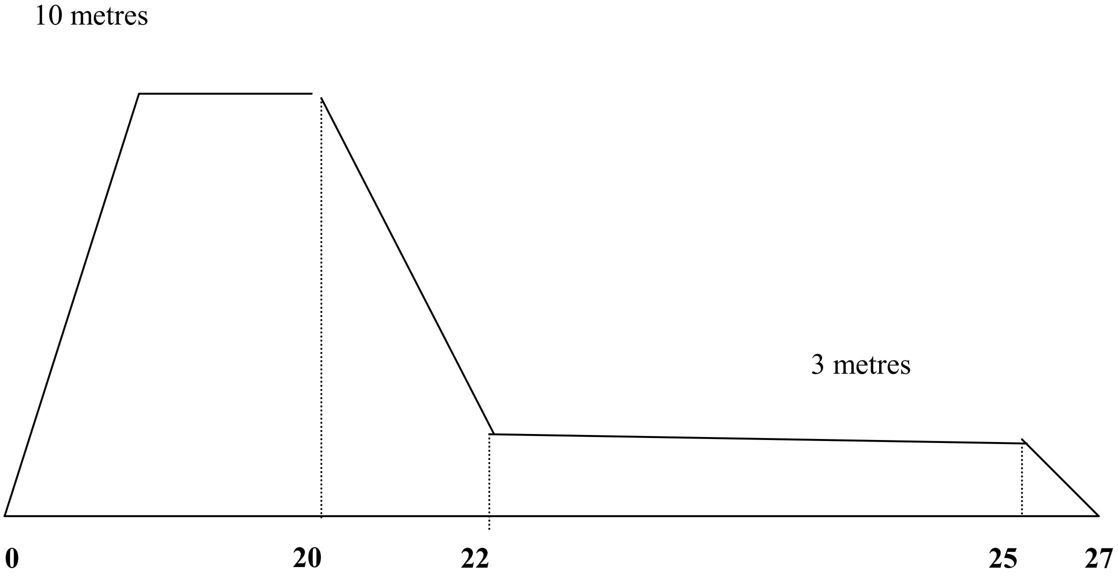
APPENDIX 5: DIVE PROFILES

DDRC Modified 10 Metres

Using DCIEM Standard Air Decompression 12 metre table 25 min Schedule. Repeat Group B on completion of dive.

Depth in Metres	Time	Breathing Mix	Elapsed Time
0-10	Total time not to exceed 20 mins	Air	Total time not to exceed 20 mins
10m		Air	
10-3m (Ascent rate 18m/min)	Total time not to exceed 2 mins	Air	Total time not to exceed 25 mins
3m	3 mins	Air/Oxygen	
3-0m	2 mins	Air/Oxygen	27 mins

Bottom Time is from Leaving Surface to Leaving Bottom
Total Bottom Time should NOT exceed 20 minutes…….
If it does then refer to DCIEM 12m table for Schedule.



On completion of dive personnel must

- Remain on site for 1 hour
- Not undergo any hard physical exertion for 12 hours
- Report any signs or symptoms of DCI in 24 hours

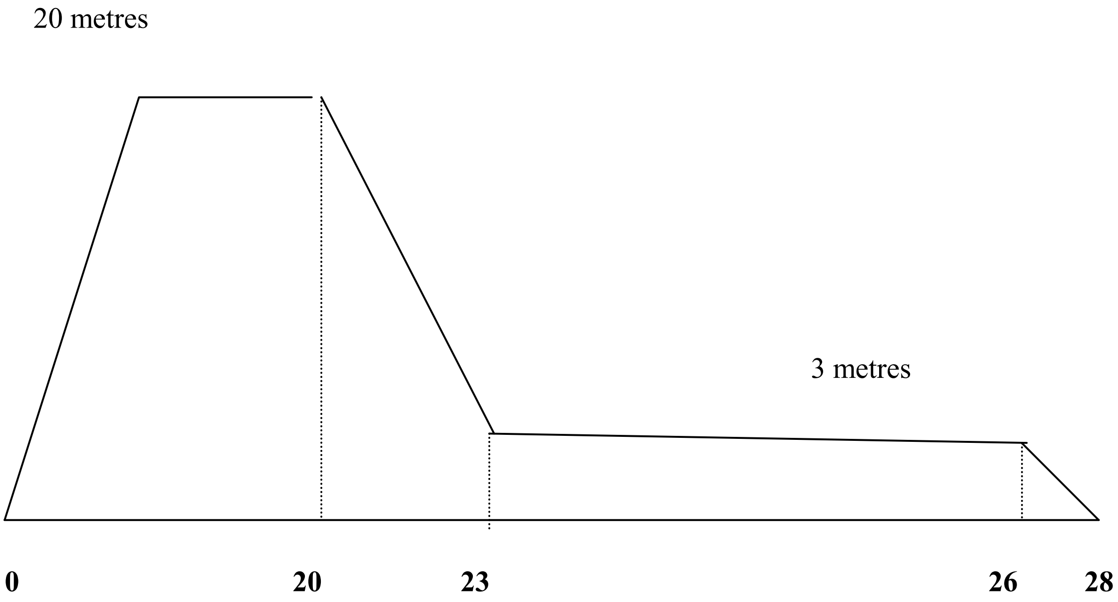
Safety Officer…………………………….

DDRC Modified 20 Metres

Using DCIEM Standard Air Decompression 21 metre table
25 min Schedule. Repeat Group D on completion of dive.

Depth in Metres	Time	Breathing Mix	Elapsed Time
0-20	Total time not to exceed 20 mins	Air	Total time not to exceed 20 mins
20m		Air	
20-3m (Ascent rate 18m/min)	Total time not to exceed 3 mins	Air	Total time not to exceed 26 mins
3m	3 mins	Air/Oxygen	
3-0m	2 mins	Air/Oxygen	28 mins

Bottom Time is from Leaving Surface to Leaving Bottom
Total Bottom Time should NOT exceed 20 minutes…….
If it does then refer to DCIEM 21m table for Schedule.



On completion of dive personnel must:
- Remain on site for 1 hour
- Not undergo any hard physical exertion for 12 hours
- Report any signs or symptoms of DCI in 24 hours

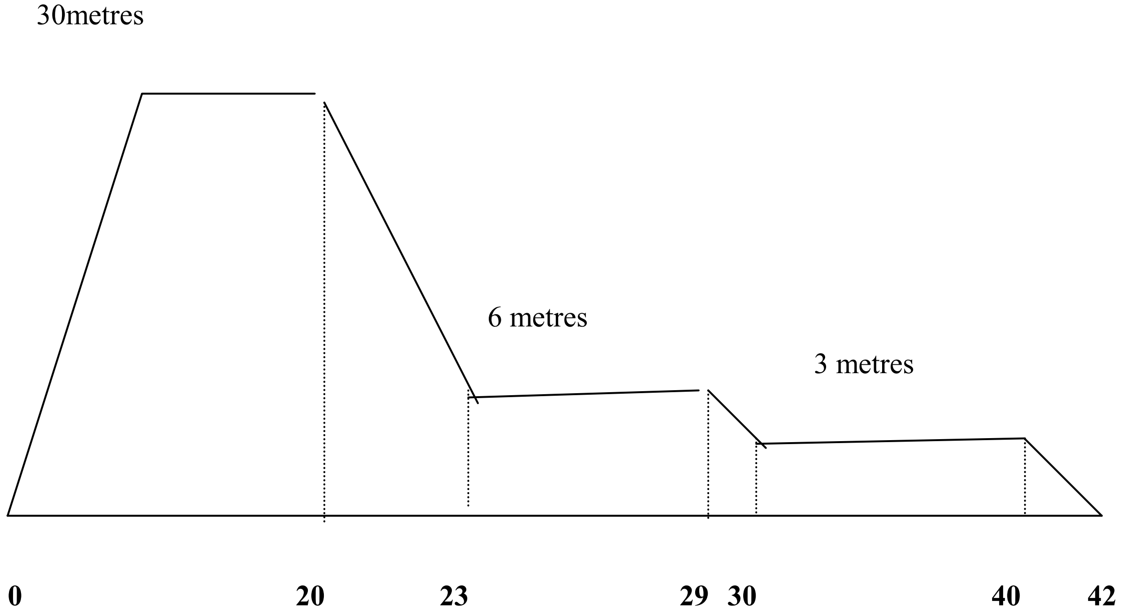
Safety Officer…………………………….

DDRC Modified 30 Metres

Using DCIEM Standard Air Decompression 33 metre table
25 min Schedule. Repeat Group H on completion of dive.

Depth in Metres	Time	Breathing Mix	Elapsed Time
0-30	Total time not to exceed 20 mins	Air	Total time not to exceed 20 mins
30m		Air	
30-6m (Ascent rate 18m/min)	Total time not to exceed 3 mins	Air	Total time not to exceed 29 mins
6m	6 mins	Air	
6-3 (Ascent rate 18m/min)	1 min	Air	Total time not to exceed 40 mins
3m	10 mins	Oxygen	
3-0m	2 mins	Oxygen	42 mins

Bottom Time is from Leaving Surface to Leaving Bottom
Total Bottom Time should NOT exceed 20 minutes…….
If it does then refer to DCIEM 33m table for Schedule.



On completion of dive personnel must:

- Remain on site for 1 hour
- Not undergo any hard physical exertion for 12 hours
- Report any signs or symptoms of DCI in 24 hours

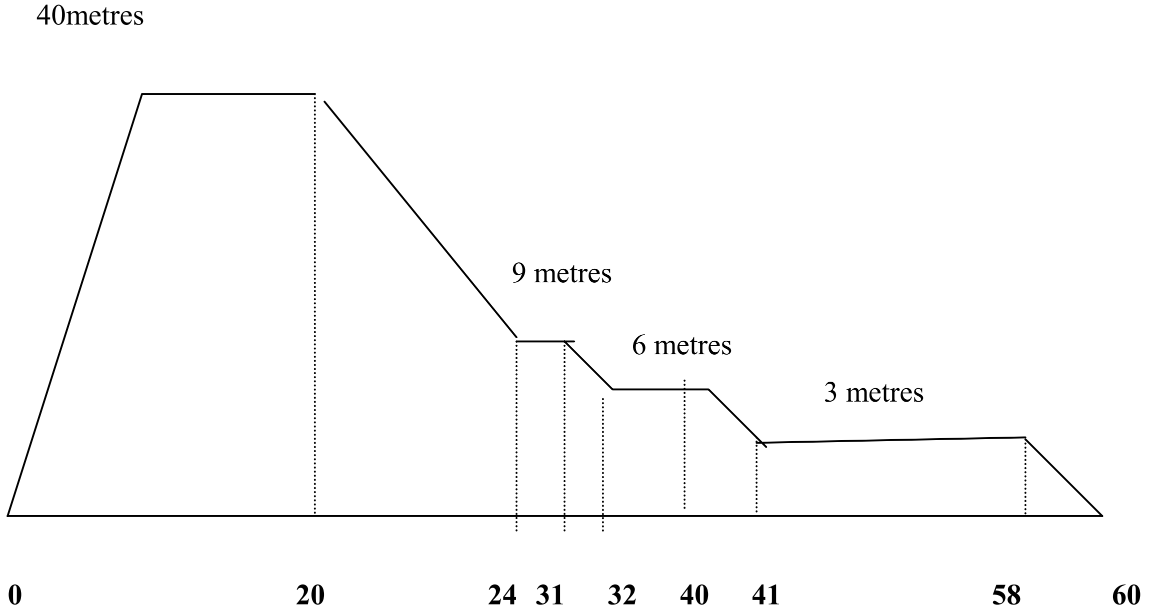
Safety Officer…………………………….

DDRC Modified 40 Metres

Using DCIEM Standard Air Decompression 42 metre table 25 min Schedule. Repeat Group K on completion of dive.

Depth in Metres	Time	Breathing Mix	Elapsed Time
0-40	Total time not to exceed 20 mins	Air	Total time not to exceed 20 mins
40m		Air	
40-9m	Total time not to exceed 4 mins	Air	Total time not to exceed 24 mins
9m	7 mins	Air	Total time not to exceed 31 mins
9-6m	1 min	Air	Total time not to exceed 40 mins
6m	8 mins	Air	
6-3m	1 min	Air	Total time not to exceed 58 mins
3m	17 mins	Oxygen	
3-0m	2 mins	Oxygen	60 mins

Bottom Time is from Leaving Surface to Leaving Bottom
Total Bottom Time should NOT exceed 20 minutes…….
If it does then refer to DCIEM 42m table for Schedule.
Ascent rate not to exceed 18m/min



On completion of dive personnel must:

- Remain on site for 1 hour
- Not undergo any hard physical exertion for 12 hours
- Report any signs or symptoms of DCI in 24 hours

Safety Officer…………………………….

APPENDIX 6: DESCRIPTIVE STATISTICS FOR SURFACE TRIALS.

Reaction Time Task –

	N	Minimum	Maximum	Mean	Std. Deviation
1st Surface	102	229.7	500.5	307.3	34.8
2nd Surface	99	221.5	391.8	303.0	31.8
3rd Surface	100	216.2	409.2	307.1	33.8
4th Surface	87	217.6	457.1	304.4	36.2

Motion Tracking Task – Distance from centre of circle

	N	Minimum	Maximum	Mean	Std. Deviation
1st Surface	102	29.3	75.3	40.8	7.8
2nd Surface	98	28.0	81.4	37.4	7.1
3rd Surface	100	28.0	61.6	37.9	6.5
4th Surface	87	29.0	58.1	37.6	6.3

Motion Tracking Task – Percentage Time spent inside the circle

	N	Minimum	Maximum	Mean	Std. Deviation
1st Surface	102	23.5	57.9	44.8	7.2
2nd Surface	98	29.2	60.4	48.5	6.7
3rd Surface	100	31.9	60.4	48.5	6.4
4th Surface	87	30.2	59.2	48.9	6.3

Word Pairs Task – Number of correct responses

	N	Minimum	Maximum	Mean	Std. Deviation
1st Surface	102	2	20	13.1	3.1
2nd Surface	98	6	20	13.7	3.0
3rd Surface	100	5	20	13.7	3.0
4th Surface	86	8	20	13.6	2.9

Word Pairs Task – Reaction Time

	N	Minimum	Maximum	Mean	Std. Deviation
1st Surface	102	965.0	2686.4	1803.8	411.5
2nd Surface	98	888.5	2731.1	1793.0	379.4
3rd Surface	100	704.5	2632.2	1765.3	384.8
4th Surface	86	1045.4	3353.5	1757.9	401.8

Letter Rotation Task – Reaction Time

	N	Minimum	Maximum	Mean	Std. Deviation
1st Surface	102	305.9	1922.7	1435.7	282.6
2nd Surface	99	498.5	2105.0	1371.8	299.3
3rd Surface	101	426.5	2225.0	1351.2	310.2
4th Surface	88	450.4	1888.1	1330.9	258.2

Letter Rotation Task – Number of correct responses

	N	Minimum	Maximum	Mean	Std. Deviation
1st Surface	102	3.3	16	13.1	2.1
2nd Surface	99	3.3	16	13.8	2.1
3rd Surface	101	4.3	16	13.9	1.9
4th Surface	88	8.3	16	14.1	1.6

APPENDIX 7: DESCRIPTIVE STATISTICS FOR METACOGNITIVE DATA OF SURFACE TRIALS.

Reaction Time Task -

	N	Minimum	Maximum	Mean	Std. Deviation
1st Pre	103	5	100	59.0	17.7
1st Post	103	24	96	54.7	12.3
2nd Pre	100	0	100	63.7	18.2
2nd Post	100	16	100	55.3	12.6
3rd Pre	100	12	100	65.5	17.1
3rd Post	100	37	98	55.8	12.3
4th Pre	87	24	100	65.8	17.3
4th Post	87	23	97	54.1	11.7

Motion Tracking Task –

	N	Minimum	Maximum	Mean	Std. Deviation
1st Pre	103	0	100	46.9	22.0
1st Post	103	0	78	26.3	18.1
2nd Pre	99	0	98	37.3	21.5
2nd Post	99	0	82	35.2	20.1
3rd Pre	101	0	81	38.8	20.3
3rd Post	101	0	97	36.8	20.0
4th Pre	88	0	91	46.3	20.6
4th Post	88	0	86	39.2	19.3

Word Pairs Task –

	N	Minimum	Maximum	Mean	Std. Deviation
1st Pre	103	0	75	35.2	19.2
1st Post	103	0	90	38.0	20.5
2nd Pre	99	0	78	38.4	19.7
2nd Post	99	0	88	41.7	20.1
3rd Pre	101	0	75	40.0	19.3
3rd Post	101	0	91	41.6	21.3
4th Pre	88	0	87	41.0	20.1
4th Post	88	0	100	41.9	23.0

Letter Rotation Task –

	N	Minimum	Maximum	Mean	Std. Deviation
1st Pre	103	25	100	62.3	16.6
1st Post	103	4	99	55.3	20.5
2nd Pre	100	11	100	55.4	19.2
2nd Post	100	7	96	57.3	19.2
3rd Pre	100	24	100	60.2	18.3
3rd Post	100	2	100	61.1	20.4
4th Pre	88	12	100	60.7	20.1
4th Post	88	23	100	62.9	19.2

APPENDIX 8: WILCOXON SIGNED RANKS TEST FOR SURFACE TRIALS.

Reaction Time Task – Pre

	1st Pre – 2nd Pre	1st Pre – 3rd Pre	1st Pre – 4th Pre	2nd Pre – 3rd Pre	2nd Pre – 4th Pre	3rd Pre – 4th Pre
P-Value	0.007	0.001	0.003	0.127	0.635	0.987

Reaction Time Task – Post

	1st Post – 2nd Post	1st Post – 3rd Post	1st Post – 4th Post	2nd Post – 3rd Post	2nd Post – 4th Post	3rd Post – 4th Post
P-Value	0.566	0.347	0.737	0.514	0.717	0.540

Motion Tracking Task – Pre

	1st Pre – 2nd Pre	1st Pre – 3rd Pre	1st Pre – 4th Pre	2nd Pre – 3rd Pre	2nd Pre – 4th Pre	3rd Pre – 4th Pre
P-Value	0.001	0.001	0.409	0.662	0.001	0.001

Motion Tracking Task – Post

	1st Post – 2nd Post	1st Post – 3rd Post	1st Post – 4th Post	2nd Post – 3rd Post	2nd Post – 4th Post	3rd Post – 4th Post
P-Value	0.001	0.001	0.001	0.847	0.057	0.315

Word Pairs Task – Pre

	1st Pre – 2nd Pre	1st Pre – 3rd Pre	1st Pre – 4th Pre	2nd Pre – 3rd Pre	2nd Pre – 4th Pre	3rd Pre – 4th Pre
P-Value	0.014	0.007	0.003	0.103	0.270	0.800

Word Pairs Task – Post

	1st Post – 2nd Post	1st Post – 3rd Post	1st Post – 4th Post	2nd Post – 3rd Post	2nd Post – 4th Post	3rd Post – 4th Post
P-Value	0.058	0.034	0.141	0.743	0.777	0.748

Letter Rotation Task – Pre

	1st Pre – 2nd Pre	1st Pre – 3rd Pre	1st Pre – 4th Pre	2nd Pre – 3rd Pre	2nd Pre – 4th Pre	3rd Pre – 4th Pre
P-Value	0.001	0.422	0.220	0.001	0.001	0.590

Letter Rotation Task – Post

	1st Post – 2nd Post	1st Post – 3rd Post	1st Post – 4th Post	2nd Post – 3rd Post	2nd Post – 4th Post	3rd Post – 4th Post
P-Value	0.365	0.001	0.001	0.016	0.001	0.664

APPENDIX 9: DESCRIPTIVE STATISTICS FOR METACOGNITIVE DEPTH TRIALS

Reaction Time Task -

	N	Minimum	Maximum	Mean	Std. Deviation
10 metres pre	49	19	100	66.8	19.8
10 metres post	49	30	100	54.6	13.7
20 metres pre	46	18	100	61.7	16.8
20 metres post	46	21	100	54.8	13.5
30 metres pre	44	30	100	64.5	18.1
30 metres post	44	21	100	54.7	14.7
40 metres pre	46	18	79	57.9	15.0
40 metres post	46	15	75	51.1	10.5

Motion Tracking Task –

	N	Minimum	Maximum	Mean	Std. Deviation
10 metres pre	49	0	88	40.9	24.0
10 metres post	49	0	85	36.2	20.6
20 metres pre	47	0	75	42.2	21.3
20 metres post	47	0	82	41.5	21.7
30 metres pre	45	0	88	37.8	24.0
30 metres post	45	0	100	38.0	23.3
40 metres pre	46	0	76	38.0	18.1
40 metres post	46	0	76	37.3	16.7

Word Pairs Task –

	N	Minimum	Maximum	Mean	Std. Deviation
10 metres pre	49	0	97	42.2	21.1
10 metres post	49	0	94	39.5	22.3
20 metres pre	47	0	75	40.6	17.7
20 metres post	47	0	87	43.0	19.9
30 metres pre	45	0	100	37.7	20.9
30 metres post	45	0	79	37.7	24.0
40 metres pre	46	0	75	39.7	19.2
40 metres post	46	0	74	39.5	20.4

Letter Rotation Task –

	N	Minimum	Maximum	Mean	Std. Deviation
10 metres pre	48	0	100	63.3	20.3
10 metres post	48	0	99	61.9	22.0
20 metres pre	46	0	100	59.5	20.0
20 metres post	46	9	91	57.8	17.9
30 metres pre	45	0	94	61.4	19.3
30 metres post	45	24	98	64.1	19.1
40 metres pre	46	0	100	56.5	20.6
40 metres post	46	10	100	55.7	20.1

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