THE EFFECT OF SUBMERSION IN WATER AND BREATHING MODALITY (ASSISTED BREATHING AND APNEA) ON DIFFERENT STAGES OF THE INFORMATION PROCESSING CHAIN

BY

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THESIS

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Abstract

Limited research has explored the impact of working underwater on the cognitive functioning of divers and even less has focused on the effect of breathing modality (assisted breathing and apnea) underwater. Research on the effect of submersion in water and apnea on cognitive performance is also very limited. As a result, the purpose of this study was to determine the effect of submersion in water and breathing modality on different stages of the information processing chain. This was achieved by testing participants in a laboratory setting under three conditions; on land, underwater with assisted breathing and underwater in apnea. Five different tests were used to determine which aspects of cognitive functioning were impaired in which condition. The recognition task result in the assisted breathing condition was significantly faster ($p=0.04$) but less accurate ($p=0.01$) than on land. The memory task was significantly ($p=0.042$) worse in terms of speed in the apnea condition compared to land, however accuracy was not affected. Performance in the visual detection task was impacted on in both underwater conditions compared to land with speed and accuracy being significantly worse ($p<0.01$) in the underwater conditions. These results indicate that simple tasks, (reaction time and tracking task) are not affected by condition whereas more complex tasks are. For tasks where an effect was found for only one condition, the effect was attributed to a specific aspect of that condition; either the breath hold or assisted breathing component of the condition. For tasks that were found to be affected in both underwater conditions, the effect was attributed to the actual submersion in water. The effect of the different conditions and the nature of the task they impact on should be considered for underwater work places as the general equipment used may impact on the quality of observations that are made.

Keys Words: cognitive performance, information processing, underwater, apnea, breath hold, assisted breathing, scuba

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1 Introduction

1.1 Background to the study

The underwater environment in itself has been seen as a potentially dangerous working environment (Baddeley, 2000), requiring a high level of situation awareness (Heywood, 2012). Situation awareness has been defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995, p. 36). High levels of situation awareness would prevent fixation on incorrect stimuli and allow divers to successfully complete the job at hand (Heywood, 2012).

The underwater environment has many inherent complications for the human information processing chain, including limited sensory input and distraction. Human information processing relies on the input of sensory information (Wickens, 1984). This requirement is affected by the reduction in number sensory modalities available when underwater (Hollien & Rothman, 1971). Human information processing is further restricted by limited attentional resources (Wickens, 1984). Attentional resources are utilised throughout information processing, from the input of information to response selection and execution (Wickens, 1984). Within the underwater environment, the input of sensory information is limited to vision as other senses are limited or negated when submerged (Hollien & Rothman, 1971). This limits the input of stimuli into the human information processing chain. In order to work in such an environment, divers and inspection engineers must use vision as their primary (and possibly only) way of assessing their work and locating dangers or risks in their vicinity. The addition of distractions, both task and environment related, alongside a task both complicates the task and opens up the possibility that attentional resources will focus on aspects that are not relevant for task completion (Wickens, 1984).

There are multiple factors that can impact on the functioning of the diver during any underwater task. A diver's situation awareness allows them to complete their task while remaining alive and is important in multiple types of diving (Heywood, 2012). How submersion affects a diver's information processing is not yet fully known, but it has been established that submersion impacts the activation of both the parasympathetic and sympathetic nervous systems (Schipke & Pelzer, 2001). These varying activations have an effect on heart rate and heart rate variability (Schipke & Pelzer, 2001); but the effects on cognitive functioning are yet to be fully established. Similarly, while many divers rely on the use of air tanks or a surface fed air supply, apnea (breath hold) diver's function in the same dangerous environment without the use of a continuous air supply, and the impact of the combined effect of submersion and apnea is not studied.

1.2 Statement of the problem

Recent research has not given much attention to the underwater workplace and even in older studies most papers that focused on functioning in the underwater environment have focused on manual dexterity in relation to pressure and temperature, visual perception and performance, work tolerances and task performance (Baddeley, 1966; Egstrom, Weltman, Baddeley, Cuccaro, & Willis, 1972; Kinney, Luria, Weitzman, & Markowitz, 1970; Kinney, McKay, Luria, & Gratto, 1970; Zander & Morrison, 2008). Few studies have focused on cognitive functioning underwater (Dalecki, Bock, & Schulze, 2012) or more specifically cognitive functioning and cold water (Mäkinen et al., 2006; Patil, Apfelbaum, & Zacny, 1995). All of the mentioned underwater based studies have used scuba (self-contained underwater breathing apparatus) diving gear in order to function underwater but the literature surrounding the effect of the use of scuba gear while underwater is limited. Research focusing on apnea and submersion has centred around physiological measures with a number of studies focusing on the human diving response (Feiner, Bickler, & Severinghaus, 1995; Francis, 1999; Gooden, 1994; Heusser et al., 2009; Lemaître et al., 2007; Walterspacher, Scholz, Tetzlaff, & Sorichter, 2011). As previously mentioned the effect of submersion and breathing modality, assisted breathing (with scuba diving gear) and apnea, on cognitive functioning is unknown, particularly during apnea diving.

1.3 Aims and objectives

The aim of this study was to quantify the effect of submersion and breathing modality (assisted breathing versus apnea) on the functioning of different stages of the information processing chain.

As a consequence, the objectives of the study were:

1) To compare performance of different information processing tasks while underwater (assisted breathing apnea) to on land.

2) To better understand the impact of different breathing modalities and submersion on cognitive performance underwater.

2 Review of literature

2.1 Introduction

Simple work systems involve the interaction of three aspects; the environment, the operator and the task. Figure 1 below demonstrates the interactions. The operator and the task interact with each other, both having an effect on the other. The environment is an overarching factor influencing both the operator and the task. This approach to work systems and the interactions of the components within the work system will be the basis of the structure of this section. The interactions between the environment in which work is conducted, the operator conducting the work, and the tasks that make up the work will be described and explained in the sections to follow.

Figure 1: Operator, task and environment interaction in a simple work system. Adapted from Oborne (1995, p. 9).

2.2 Environment

The environment is the area in which any work is taking place. Therefore with regards to underwater work the environment is the area within the body of water that work is taking place. This section will expand on the nature of the environment in which underwater work takes place (2.2.1) and the associated risks (2.2.2).

2.2.1 Underwater workplaces

Underwater workplaces, although in a constant medium, vary greatly between job types. Jobs such as off shore inspection engineers require the divers to possess more than just the ability to dive and function underwater but to make informed decisions and report on any issues identified (Australian Government - Department of Education and Training, n.d.). Underwater inspection tasks are also performed on water front facilities such as piers, pilings, wharves and quay walls (Kelly, 1999). The construction of the structure (the size, shape and materials used to build it) influence the inspection process as different materials are susceptible to different types of damage and require different equipment to be inspected thoroughly (Kelly, 1999). Experience is a requirement for most underwater jobs, especially off shore, usually requiring one year or more (Australian Government - Department of Education and Training, n.d.). Divers' typical workplace tasks include basic operations of a diver (e.g. underwater observer), carrying out underwater tasks that are deemed necessary, and identifying and reporting any issues found (Global Diving & Salvage, 2015).

2.2.2 Dangerous environments

In addition to the submersion in water and the associated pressure changes many inspection tasks underwater are carried out in a dangerous environment. The possible presence of predators in the water (specifically in seas and oceans) increases the risk to the diver. The presence of a danger can reduce efficiency in all but the most experienced subjects (Baddeley, 2000), as the presence of a danger heightens arousal levels which in turn narrows the focus of attention. The attention is focused on what the diver considers the most important aspect of the task, however if the danger is deemed as the most important aspect of the task the task performance will be reduced (Baddeley, 2000). However, no attention paid to the danger will be as, if not more, detrimental to the task as it is to the diver. If the diver pays no attention to the danger, they may not return from the task and the task will remain incomplete.

2.3 Operator

The operator is any person in the environment tasked with or involved in any aspect of the work performed in the environment. This section expands on the functioning and processing abilities of the operator and the impact that the operating environment has on the operator, their functioning and the processes that can be affected. The most important aspects of the human operator underwater are the physiological effects of being underwater (2.3.1), the effect of water on vision (2.3.3), breathing modalities (2.3.4) and the changes of human information processing underwater (2.3.5 and 2.3.6). These will be discussed in the following paragraphs.

2.3.1 Physical effects of being underwater

The underwater environment presents many challenges to the diver. There is a higher viscosity of medium to move through (Dalecki et al., 2012), colder temperatures (Egstrom et al., 1972) and higher pressure (Baddeley, 1966). Divers are also limited in multiple aspects when underwater. Their vision is obscured and their visual field is restricted, the equipment they are wearing may restrict their movement and they must cope with the weightlessness of the environment (Baddeley, 1966). As divers operate in deeper water, the temperatures they are exposed to are lower and the pressure is higher, adding other factors the divers must overcome to operate in the environment. This can have an impact on manual dexterity as any work conducted in colder, deeper water would result in a large impairment to the diver's manual dexterity. The depth at which a diver operates may affect the nature of the task they are able to complete. The deeper the diver goes, the higher the pressure exerted on the diver's body. As a result simpler tasks that do not require high levels of manual dexterity are more easily performed in higher pressures (Baddeley, 1966). The presence of cold water, causing localised cooling reduces a divers' manual performance, namely grip strength, tactile sensitivity and manual dexterity (Zander & Morrison, 2008).

The lower temperature impacts on processes other than manual dexterity. Studies using exposure to cold air found that moderate cold exposure had both positive and negative impacts on cognition (Mäkinen et al., 2006). The negative effects are due to mechanisms of distraction and arousal. The mechanism of arousal can also have a positive effect on cognitive function (Mäkinen et al., 2006). Cold exposure specifically affects several cognitive skills, both simple and complex, including but not limited to; sustained attention and concentration, reasoning and the operation of the working memory (Mäkinen et al., 2006). The reduction in mental performance, linked to both submersion and the presence of a cold stressor, places the diver at risk.

The human diving response comes into effect when the diver enters the water (Gooden, 1994). This response is the interaction of multiple reflexes within the body (Gooden, 1994), causing activation of the parasympathetic nervous system (Schipke & Pelzer, 2001). The human diving response involves bradycardia taking place in the body (Gooden, 1994; Landsberg, 1975; Schipke & Pelzer, 2001). This slowing of the heart rate is an oxygen conserving response to immersion and submersion. Linked to the bradycardia is an increase in heart rate variability (HRV). The HRV of divers has been found to increase during immersion and submersion (Schipke & Pelzer, 2001).

2.3.2 Vision

Anatomy and physiology of the eye

All human vision is contained within the eyes. The human eyes are two spheres, approximately 2.5 centimetres in diameter (Tortora & Derrickson, 2009). The eyes are composed of three layers (Rizzo, 2006). The three layers are the fibrous tunic, vascular tunic and the retina (Seely, Stephens, & Tate, 2006; Tortora & Derrickson, 2009). The fibrous tunic is made up of the cornea and the sclera (Rizzo, 2006; Seely et al., 2006; Tortora & Derrickson, 2009). The vascular tunic is the middle layer of the eye and contains the ciliary muscles connected to the lens of the eye, the iris and choroid – the portion of the vascular tunic associated with the sclera (Rizzo, 2006; Seely et al., 2006; Tortora & Derrickson, 2009). The lens of the eye is perfectly transparent and focuses the image onto the retina (Tortora & Derrickson, 2009). The last and innermost layer of the eye is the retina (Seely et al., 2006). The retina forms the posterior three quarters of the eye ball (Tortora & Derrickson, 2009). Only a small portion of the eyes are exposed to the outside resulting in all visual information coming from a small exposed area.

The eyes form part of the visual system, which includes the optic nerves, tracts, pathways and accessory structures of the eye (Seely et al., 2006). Information from the eyes is relayed to the brain via the optic nerves (Seely et al., 2006). The image received from the eyes by the brain is inverted, however processes in the brain correct the image (Tortora & Derrickson, 2009). The overlapping visual fields of the two eyes is the area of binocular vision which enables depth perception (Seely et al., 2006).

The process of vision begins with the photopigments of the eye absorbing light entering the eye (Tortora & Derrickson, 2009). The photopigments in the eye are coloured proteins that absorb light, causing structural changes in the protein (Tortora & Derrickson, 2009). There are two types of photopigments in the eye; rods and cones (Tortora & Derrickson, 2009). Rods contain rhodopsin (Rizzo, 2006; Seely et al., 2006) and cones, of which there are three variants, each contain a different photopigment (Tortora & Derrickson, 2009). The different cone photopigments activate when exposed to different wavelengths of light, enabling colour vision (Tortora & Derrickson, 2009).

Visual photopigments contain a vitamin A derivative called a retinal (Seely et al., 2006; Tortora & Derrickson, 2009), and a glycoprotein called opsin (Tortora & Derrickson, 2009). The retinal absorbs the light and the opsin determines the wavelength of light absorbed (Tortora & Derrickson, 2009). There are four types of opsin present in the eye; rhodopsin in the rods (Rizzo, 2006) and three in the cones, one for each type of cone (Tortora & Derrickson, 2009).

Before the absorption of light the retinal is bent in shape, called a *cis-retinal* (Tortora & Derrickson, 2009). After the absorption of light the retinal changes to a *trans-retinal* (Seely et al., 2006). A *trans-retinal* is a straightened out *cis-retinal* (Seely et al., 2006). This change is known as isomerisation and is triggered by the absorption of one photon of light (Tortora & Derrickson, 2009). The change also causes a change in the shape of the opsin, which activates the G protein attached to the opsin in a process known as transduction (Seely et al., 2006).

After approximately one minute, bleaching takes place when the *trans-retinal* completely separates from the opsin, and the final product appears colourless, hence the term bleaching (Tortora & Derrickson, 2009). Retinal isomerase is the enzyme that converts the *trans-retinal* back to a *cis-retinal* (Tortora & Derrickson, 2009). After bleaching, regeneration takes place. Regeneration is the process by which a functional photopigment is reformed. This happens when a *cis-retinal* binds with an opsin (Tortora & Derrickson, 2009). Regeneration takes different lengths of time for rods and cones. Cones regenerate at a faster rate with rod regeneration taking up to forty minutes (Tortora & Derrickson, 2009).

The visual pathway

All information that travels from the eyes to the brain is first generated within the eye. Inside the eye chemical changes that occur during isomerisation arise in the outer segments of rods and cones and these changes generate receptor potentials (Tortora & Derrickson, 2009). From the outer segments the receptor potentials spread to the inner segments of the rods and cones and from there spread to the synaptic terminals (Tortora & Derrickson, 2009). Rods and cones synapse with bipolar cells, which synapse with ganglion cells (Seely et al., 2006). Bipolar cells synapse with multiple rods whereas cones tend to synapse with a single bipolar cell (Tortora & Derrickson, 2009). The result of these ratios is that rods are highly sensitive to light but result in a blurred image on the retina and cones are less light sensitive but have a much sharper and clearer image (Seely et al., 2006; Tortora & Derrickson, 2009).

Photoreceptor and bipolar cells synapse with horizontal cells (Seely et al., 2006). Horizontal cells increase the contrast between weakly and strongly stimulated areas of the retina by generating inhibitory signals lateral to excited rods and cones (Tortora & Derrickson, 2009). The excitatory or inhibitory effect that occurs enhances contours and boarders, increasing the intensity at boundaries (Seely et al., 2006). In cones' horizontal cells enable colour differentiation (Tortora & Derrickson, 2009).

Ganglion and bipolar cells synapse with amacrine cells (Seely et al., 2006). Amacrine cells are excited by bipolar cells causing the amacrine cells to synapse with the ganglion cells and in doing so signal changes in the illumination of the retina (Tortora & Derrickson, 2009). Nerve impulses are initiated at ganglion cells, when signals are transmitted from bipolar or amacrine cells to the ganglion cells, which then depolarize (Tortora & Derrickson, 2009). The ganglion cells converge at the optical disc and exit the eye as the optic nerve (Rizzo, 2006; Seely et al., 2006). The optic nerve transmits the nerve impulses to the brain (Seely et al., 2006).

2.3.3 Vision underwater

A diver's ability to see is paramount to the performance of their job as one of a diver's main roles is that of an underwater observer (Egstrom et al., 1972). Seeing underwater is one of the challenges faced when exploring the seas and oceans (Luria & Kinney, 1970). The distortions faced by divers' underwater impacts on their ability to perform their jobs. Radiant energy is changed underwater (Luria & Kinney, 1970), and the transmission of light through water distorts the image (Kinney, Luria, & Weitzman, 1968; Kinney, McKay et al., 1970)

The ability to discern size and distance is linked to stereoscopic acuity. Size and distance are overestimated underwater (Luria, Kinney, & Weissman, 1967), and distances are also overestimated in the absence of distinct cues. This is due to the image on the retina being enlarged underwater (Luria & Kinney, 1968, 1970). Water turbidity is linked to the clarity of the water and any materials or particulates in suspension in the water. Turbidity can be affected by the weather, disturbances to sediment and movement in the water. Stereoscopic acuity is degraded in water and generally worsened with increased water turbidity (Luria & Kinney, 1968). The drop in stereoscopic acuity is linked to the loss of peripheral cues underwater (Luria & Kinney, 1968). Visual functions underwater may be effected by the Ganzfeld effect (Luria & Kinney, 1968), which has been found to play a significant role in the degradation of stereoscopic acuity. The Ganzfeld effect is caused by exposure to a structureless visual field and can result in the person seeing the blood vessels of the eye or suffering from hallucinations, given enough exposure time to the structureless field (Avant, 1965).

The distortions experienced underwater effect novice divers the most with these divers not finding objects where they appear to be (Kinney, McKay, et al., 1970). This changes with experience, as highly experienced divers react to the physical location of the object rather than its visual location. This response appears to be conscious and a factor of experience (Kinney, McKay, et al., 1970). The adaptation to compensate to underwater distortions is a two stage process; the first stage is rapid and occurs automatically and the second stage is a long term adaptation (Kinney, McKay, et al., 1970). The first stage of adaptation takes place due to being in the water and performing any tasks (Kinney, McKay, et al., 1970). The second adaptation takes place over time and involves the learning of new visual-motor coordination (Kinney, McKay, et al., 1970). Kinney et al. (1970) found that a 15 minute session of spaced interval underwater tasks afforded the divers a near one hundred percent adaptation. Although the adaptation in the study by Kinney et al. (1970) was achieved in a 15 minute session the results obtained did not indicate a minimum time in which the adaptation be achieved or whether the adaptation is long lasting.

2.3.4 Mode of breathing

Normal breathing

Normal breathing occurs through daily life in an often unconscious manner. The process by which normal breathing takes place is through differing pressures between the internal environment of the lungs and the outside air pressure following Boyle's law (Tortora & Derrickson, 2009). Inhalation takes place when the pressure inside the lungs is lower than that of the outside environment. This is achieved by increasing the size of the lungs, generating a negative pressure inside the lungs (Tortora & Derrickson, 2009). The increase in the size of the lungs is achieved through muscular effort of the respiratory muscles (Tortora & Derrickson, 2009). After inhalation, exhalation takes place, which also occurs through a pressure gradient and is, during normal relaxed breathing, a passive process as there is no muscular effort required (Tortora & Derrickson, 2009). As the inspiratory muscles relax and return to their normal position they reduce the size of the lungs, increasing the internal pressure in the lungs (Tortora & Derrickson, 2009). This increase in pressure causes the air to flow outwards, traveling from an area of high pressure, inside the lungs, to an area of low pressure, the outside air environment (Tortora & Derrickson, 2009). Exhalation becomes an active process when air is forcefully removed from the lungs by the inspiratory muscles. This occurs during activities such as exercise (Tortora & Derrickson, 2009).

Apnea

A select subgroup of divers operate within the underwater environment without any form of air supply. These divers perform all of their underwater activities while holding their breath, in apnea. Examples of breath hold divers are spear fishermen. Studies that have been conducted on breath hold divers have focused on the human diving response (Gooden, 1994), cardiovascular regulation, respiratory function and physiological responses (Heusser et al., 2009; Lemaître et al., 2007; Walterspacher, Scholz, Tetzlaff, & Sorichter, 2011), hypoxia (Feiner et al., 1995), bradycardia (Landsberg, 1975) and manual dexterity (Baddeley, 1966). The effects of submersion and working underwater are known but these studies all had the participants breathing normally, either through a snorkel, surface fed air supply or scuba system at the time. Elite breath hold divers can perform a static apnea for up to 7 minutes and 49 seconds (Walterspacher et al., 2011). The world record listed as of 2010 by the Association Internationale pour le Développement de l'Apnée (AIDA) is 11 minutes and 35 seconds (Association Internationale pour le Développement de l'Apnée, 2010). Other records kept by the AIDA are for depth reached with breath hold, of which the record is currently held at 214 metres (Association Internationale pour le Développement de l'Apnée, 2010). Breath hold triggers an increase in muscle sympathetic nerve activation and this increase is far greater in trained breath hold divers than in non-divers (Heusser et al., 2009). Heusser et al. (2009) explains that the breath hold coupled with face immersion in cold water would increase the sympathetic activity. Whereas, parasympathetic nervous system activation during diving would be triggered by the human diving reflex (Heusser et al., 2009; Schipke & Pelzer, 2001).

Breath hold diving is involved in many activities where the diver is in a potentially dangerous environment. The dangers that may be faced include predators, extreme depth (pressure), underwater currents and rock or coral dangers on reefs. Submersion and cold temperatures have been shown to have a negative impact on the mental performance of subjects in those conditions (Mäkinen et al., 2006). These effects have been tested in isolation and therefore the effect of breath hold coupled with submersion and cold temperatures is unknown. The effect of submersion and breath hold on cognitive performance is not well studied and as a result not well understood.

Assisted breathing

Assisted breathing diving comes in two main forms, surface fed air supply or scuba (Self-Contained Underwater Breathing Apparatus) diving. Both these methods involve the user breathing 'normally' throughout their dive time. Scuba diving is a popular recreational mode of diving and is also used in many other fields such as salvage, research or military applications. During the course of diving with scuba gear, breathing is made possible by the air tank, containing pressurised air (PADI, 2005). Breathing the compressed air is then made possible by the regulator, a demand valve connecting the air tank to the diver (PADI, 2005). When breathing, the inhale action of the diver opens a valve in the regulator allowing air to flow from the regulator to the diver (PADI, 2005). This means the diver is breathing in compressed air. The compressed air flowing into the lungs is different to breathing on the surface as the compression pushes the air into the lungs as opposed to air being drawn into the lungs. Exhalation during this process operates with the same mechanism as normal breathing but the pressure difference between the inside and outside environments is greater due to the use of pressurised air. The release of the pressurised air from the regulator causes noise which is the movement of the compressed air. This noise or feedback causes an increase in the parasympathetic nervous system activation (Schipke & Pelzer, 2001). Along with the increase in HRV during immersion and submersion in water, the use of scuba gear can further increase HRV (Schipke & Pelzer, 2001). As a result scuba diving increases both the activation of the sympathetic and parasympathetic nervous systems.

2.3.5 Cognitive performance

Basics of human information processing

Human information processing is a sequence of processes and feedback loops whereby information received is transformed or utilised over time by the different stages in the process to come to an output or response (Wickens, 1984). The utilisation or transformation of the received information requires attentional resources in order to be processed (Wickens, 1984). Attentional resources are limited and as a result human information processing is limited in the number of tasks that can be performed concurrently (Wickens, 1984).

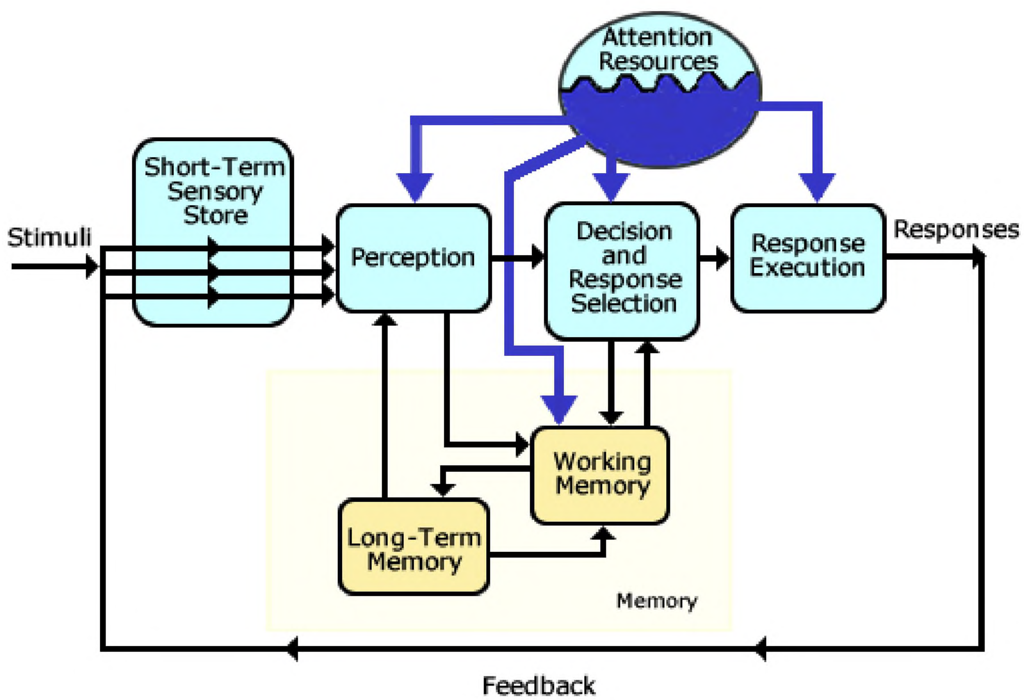


Figure 2: A Model of Human Information Processing. Adapted from Wickens (1984, p. 12).

Figure 2 displays a model of human information processing. Human information processing is a sequential process; from the input of information, perception of it, followed by decision making and ending with a response execution. Each of these stages requires attention, which is limited. Decision making requires memory which is also limited (Wickens, 1984). As a process is conducted more it tends towards becoming more automatic and the attentional resources required to perform it become less (Wickens, 1984). Tasks such as changing gears while driving become automatic processes as the action requires less resources to perform the more one becomes accustomed to performing the actions. However, tasks that require the same attentional resources or senses cannot be effectively performed together as one task will constantly have to take priority and this results in there being less resources available to be used for other tasks (Wickens, 1984). Due to this relation, multitasking becomes difficult and if one of the tasks requires a high amount of attentional resources, multitasking becomes impossible.

There are three types of attention that are utilised by people for different aspects of the information processing chain; selective attention, focused attention and divided attention (Wickens, 1984). All three have their limitations (Wickens, 1984). Attentional resource allocation and the types of attention are affected by outside factors such as stress (Wickens, 1984). During selective attention tasks, where attention must be focused on one or a few of many possible stimuli, high stress situations can cause inappropriate sampling and information selection, (Wickens, 1984).

The practical implications of focused and divided attention come into play during visual searches and target acquisition as locating a target against a complex background, combines characteristics of both focused and divided attention (Wickens, 1984).

Memory and recall

All memory is subject to decay. The rate of decay is affected by the number of items that must be remembered (Wickens, 1984). As the number of items to remember increases, the rate at which the memory decays also increases (Figure 3). As a result, the more a diver has to remember the faster the decay rate of the memory.

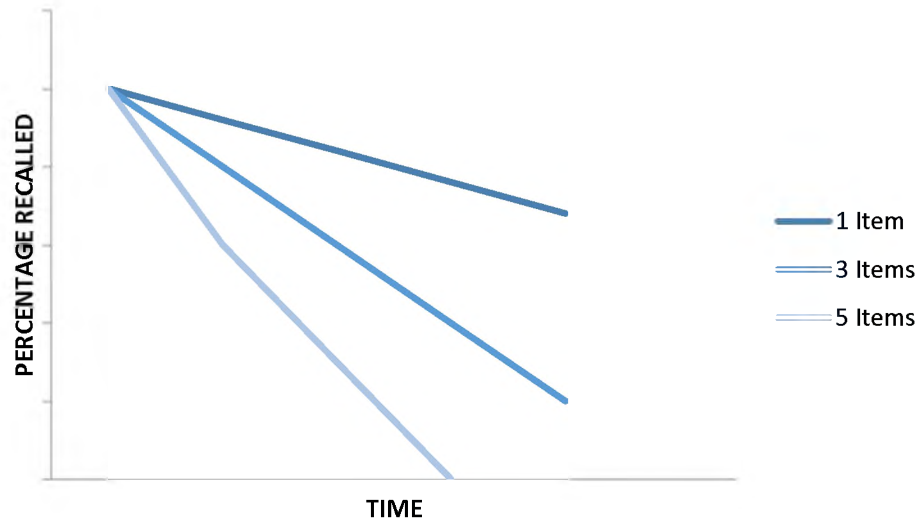


Figure 3: Memory decay over time depending on the number of items to be remembered. Adapted from Wickens (1984, p. 218).

Context as well as emotion have an impact on memory (Gooden & Baddeley, 1975). The recall of a diver's inspection task once back on surface is reduced due to the change of environment, with information being best remembered in the context in which it was learnt (Smith, 1979). The underwater environment is as different to any environment that can be found on Earth and is still a natural environment (Gooden & Baddeley, 1975), it is seen as an "unforgiving alien world" (Heywood, 2012). The phenomenon of context-dependent learning is robust and can affect normal behaviour and performance (Gooden & Baddeley, 1975). Egstrom et al. (1972) found that divers had difficulty recalling material learnt underwater. Recognition memory was found to not be impaired and it was concluded that the defect was probably due to a context dependent memory effect. The conclusion of the study by Egstrom et al. (1972) was speculative as the appropriate controls were not included (Gooden & Baddeley, 1975).

Humans process information in different ways depending on what is required by the task. Automatic scans are rapid and the target object 'jumps out' at the observer, whereas a controlled process is slower and more serial (Wickens, 1984). The three levels of inspection for underwater inspection tasks are: Level 1 – general visual inspection (locating obvious damage), level 2 – close-up inspection (detailed investigations) and level 3 – highly detailed inspections (Kelly, 1999). The varying levels of inspection specified by Kelly (1999) are relatable to the types of processing described by Wickens (1984), going from a more automatic scan through to a slower serial scan. Any inconsistencies in the measurements or observations made by a diver and not confirmed by the second diver warrant the entire task be repeated (Kelly, 1999).

Underwater work is often characterised by a dangerous environment, and this may result in the diver experiencing a higher level of stress even fear. Fear being negative emotion results in the subject focusing attention on the threatening aspects of a memory (Talarico, Berntsen, & Rubin, 2009). A focusing of attention on the threatening aspects of a memory reduces the ability of a person to recall the core aspects of a memory as focus is taken away from the information that the diver should be reporting to the surface as part of their inspection task. Along with negative impacts on memory, orientation, decision making, work productivity and reactions in challenging situations are all crucially affected by mental performance (Mäkinen et al., 2006).

2.3.6 Situation Awareness

"Situation Awareness is the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995, p. 36). Situation awareness was first identified by Oswald Boelke during World War I (Stanton, Chambers, & Piggott, 2001). Despite its early identification situation awareness did not receive much academic attention until the late 1980's (Stanton et al., 2001). The major driving force in the development of research into situation awareness was the aviation industry (Stanton et al., 2001). The pressure placed on air traffic controllers and pilots lead to the development of better situation awareness. This development of understanding and use of situation awareness was triggered by the realisation that the system design pilots and air traffic controllers were dealing with was no longer optimal for human operation. The development of situation awareness research has coincided with the increase in levels of automation within the aviation industry (Stanton et al., 2001).

For safety reasons situation awareness is critically important for diving in recreational and occupational settings (Heywood, 2012). Situation awareness in diving is seen as an advanced skill as divers must be acutely aware of their surroundings while continually monitoring their depth, time and decompression status (Heywood, 2012). The key dive strategy has always been to 'breathe always and never hold your breath' but it is suggested this change to 'breathe always, never hold your breath and always look around' (Heywood, 2012). This change to the strategy is an effort to increase situation awareness and combat attentional tunnelling, the fixation on one set of information at the cost of others (Heywood, 2012). Poor situation awareness may lead to risks and dangers around the operator going unnoticed and as a result the task and operator's wellbeing are put at risk. Good situation awareness prevents the operator from fixating on certain information, enabling them to be aware of their entire surroundings, which leaves them able to respond to most events correctly. Situation awareness improves with good observation and awareness of one's surroundings. Chiasson, McGrath & Rupert (2002) investigated the use of a tactile feedback system to enhance situation awareness and improve navigation abilities without compromising the user's ability to visually assess their environment. For the underwater environment the tactile navigation system can be used to perform more accurate navigation and with the correct sensors being fitted, the system would be able to inform the user of the position of other divers and the presence of possible threats (Chiasson et al., 2002).

2.4 Task

The task is any form of operation performed during work to accomplish a goal. This section will discuss the nature of the tasks that are conducted in the underwater environment (2.4.1) and how these tasks may be assessed (2.4.2).

2.4.1 Inspection tasks underwater

Inspection tasks are, in general, a mainly visual checking process culminating in a discrimination decision (Goebel, Zschernack, & Yoo, 2006). Inspection tasks are and always have been a part of human work, becoming a mostly organised specific task in industry (Goebel et al., 2006). Inspection tasks have been used in providing rapid feedback (Goebel et al., 2006). Although an inspection task is a mainly visual checking process, other perception modalities can be used (Goebel et al., 2006). In this regard underwater inspection tasks are complicated as the use of perception modalities other than vision, such as auditory, haptic or olfactory sentences, are limited (Hollien & Rothman, 1971). The reliability of observations during any inspection task is key as the task concludes with a decision (Goebel et al., 2006). The accuracy and reliability of inspection task data being critically important is true for all forms of an inspection task, including inspection tasks underwater (Kelly, 1999). The use of perception modalities during an inspection task, regardless of which modalities, requires attentional resources to be performed (Wickens, 1984). This is complicated for underwater inspection tasks as there is an altered visual field and the possible presence of other stressors to the visual system, such as the Ganzfeld effect, which can detract from a person's ability to focus on a task while underwater. This coupled with the fact that attentional resources are limited (Wickens, 1984), any distraction from the inspection task would reduce the amount of attentional resources dedicated to the task. This impacts on underwater inspection tasks as they follow a specific criteria and the usefulness of their findings are highly dependent on the reliability and suitability of the data collected (Kelly, 1999). As a result underwater inspection tasks are always corroborated by a second inspector/diver and any discrepancy in the findings of the two inspectors will result in the entire inspection task being redone (Kelly, 1999).

2.4.2 Assessment of performance underwater

Assessment of performance underwater depends on what aspects of underwater performance are being tested. The assessment of visual distortions underwater has been done without the subject having to physically be in the water during the testing (Kinney et al., 1968).

For underwater inspection tasks the assessment of performance is two stage; the first stage of assessment is the confirmation of a diver's observations by a second diver (Kelly, 1999). The second stage of assessment comes about when the structure or surface being inspected is repaired or not. If the repairs take place and no failures occur the inspection was completed successfully and accurately. Should any failures occur the inspection conducted by both divers was not completed fully or accurately. In the event of an incorrectly or incompletely performed inspection, the consequences are extremely severe and potentially life threatening (Kelly, 1999).

3 Methodology

The aim of the current study was to assess the effect of submersion in water and breathing modality (assisted breathing and apnea) on different stages of the information processing chain. Ethical approval for the study was obtained from the Department of Human Kinetics and Ergonomics Ethics Committee.

3.1 General experimental concept

In order to investigate the effect of submersion and breathing modality (assisted breathing and apnea) on different stages of the information processing chain, participants were tested underwater on a series of cognitive tasks. The testing took place in a laboratory setting. Participants were tested under two underwater conditions (assisted breathing and apnea) with testing on land being the third condition. All the participants were tested under all three of the conditions (repeated measures experimental design). The testing conditions and breathing modality were the independent variables of the study. During the testing conditions participants performed different information processing tasks, of varying difficulty, to assess the extent of the effect of submersion in water on information processing. The participant's performances in the different information processing tasks were the dependent variables of the study. The performance variables were the only variables measured during testing as there was no equipment capable of collecting physiological responses underwater available. The majority, four of five, of the tasks involved two levels of difficulty. This was done in order to determine if the particular resource required by the task was taxed by the condition. To isolate the effect of being underwater and of breathing modality, the temperature of the water and light conditions were controlled. Additionally the testing stations for the underwater and on land conditions were identical.

3.2 Hypothesis

The main hypothesis proposed for this study was that performance in different stages of the information processing chain will differ between the three conditions; on land, underwater with assisted breathing, and underwater with apnea.

While there was an expectation that performance would decline underwater there was not enough evidence in literature to suggest that this was to be expected nor was there a model that would explain why such a decline should be expected. Therefore, it was chosen to formulate the hypothesis undirected.

The secondary hypotheses for the study were:

Performance in the higher difficulty version of the task, where applicable, would have reduced performance compared to the lower difficulty version.

Performance would change over time in each of the tasks across the three conditions.

1. Performance of the test battery would be different between the three conditions; on land, underwater with assisted breathing and underwater with apnea.

Alternative hypothesis: There will be a difference in performance in the test battery between the land, underwater with assisted breathing and underwater with apnea conditions.

H_1: $\mu T_L \neq \mu T_{AB} \neq \mu T_A$

Null hypothesis: There will be no difference in performance of the test battery between the land, underwater with assisted breathing and underwater with apnea conditions.

H_0: $\mu T_L = \mu T_{AB} = \mu T_A$

Where:

T – test battery performance

L – land

AB – underwater with assisted breathing

A – underwater with apnea

2. Performance in the test battery will differ between the two levels of difficulty.

Alternative hypothesis:	There will be a difference in performance in the test battery between the two difficulties.
	H_1: $\mu T_H \neq \mu T_L$
Null hypothesis:	There will be no difference in performance of the test battery between the two difficulties.
	H_0: $\mu T_H = \mu T_L$

Where:

T – test battery performance

H – high difficulty

L – low difficulty

3. There will be an effect of time on the performance in the test battery

Alternative hypothesis:	There will be a difference in performance in the test battery over time.
	H_1: $\mu T_{t1} \neq \mu T_{t2}$
Null hypothesis:	There will be no difference in performance of the test battery over time

$$H_0: \mu T_{t1} = \mu T_{t2}$$

Where:

T – test battery performance

t1 – beginning of test battery

t2 – end of test battery

3.3 Conditions

The independent variables of this study included, among others, the three testing conditions of; on land, underwater with assisted breathing and the underwater with apnea.

The first underwater condition had the participants using assisted breathing in the form of scuba equipment to breathe while underwater. The second underwater condition had the participants holding their breath (in apnea). During all of the conditions, including the third on land condition, participants completed the same test battery.

3.4 Test battery

3.4.1 Visual detection task

The visual detection task used in this study taxed the visual system while measuring stimulus recognition (Goble, 2013). The objective of the test was to identify one red stimulus, the critical stimuli, among multiple white stimuli. All the stimuli were 2 mm x 2 mm and star shaped (Goble, 2013). There were two levels of difficulty used in this task (Figure 4). In the high difficulty level there were 80 stimuli present on the screen (Goble, 2013). In the low difficulty level 40 stimuli were present on the screen (Goble, 2013). The participant was required to respond to the critical stimulus using the computer keyboard, left clicking when it was identified. The critical stimulus appeared at varying spatial orientations on the screen at random intervals between 300 and 1000 ms. The task was displayed on a 17” Philips LCD monitor. The task duration was 60 seconds, divided into two 30 second sessions.

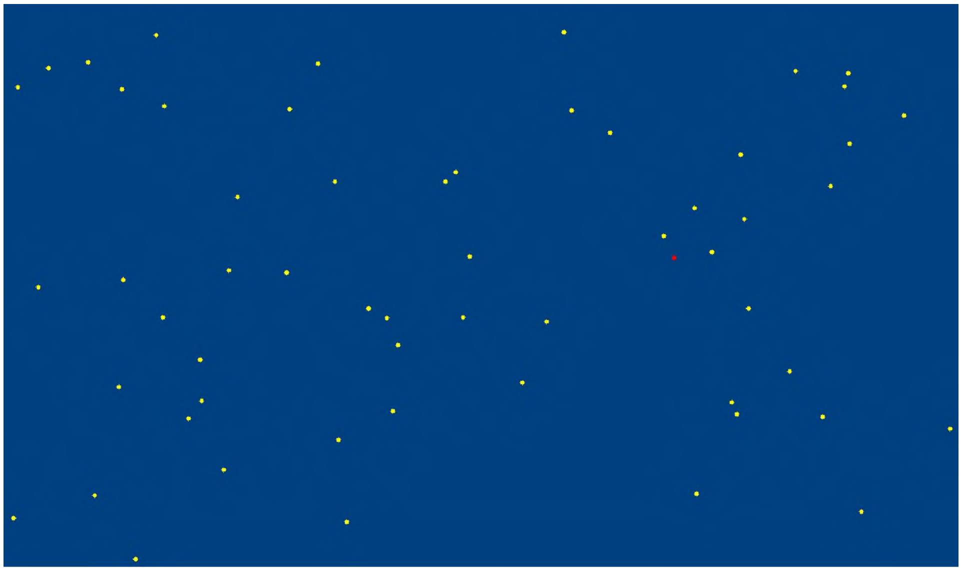


Figure 4: Visual detection task. Low difficulty consisted of 40 star shaped stimuli present on the screen, high difficulty consisted of 80 stimuli.

3.4.2 Reaction time

A stimulus response task was used in the study to assess reaction time. The stimulus response task was a modified Fitts' task (Fitts, 1954). There were two levels to the task, simple and choice reaction time. In the simple reaction time task a green, circular stimulus (50mm in diameter) appeared randomly in the centre of the screen (Philips 17'' LCD). Participants were instructed to left click when the stimulus appears. To assess choice reaction time a modified stimulus response task was used (Sunshine, 2013). In this test a green circular (30 mm in diameter) or blue square stimulus (30 mm length and width) appeared randomly in the middle of the screen. Participants were instructed to left click if a green circular stimulus appeared and right click if a blue square stimulus appeared. The presentation time of the stimuli varied between 300ms and 1000ms. The test duration was 30 seconds, once off, for each difficulty.

3.4.3 Memory recall: Digit span task

A memory recall task was used to test working memory (Tichiwanhuyi, 2015). The memory recall task was computer based and was presented on the PEBL software. Participants were required to memorise a string of digits that were presented visually. The number of digits in the string presented varied depending on task difficulty. For the low difficulty task five digits were presented and for the high difficulty task seven digits (Figure 5). The string of digits was presented on a computer screen (Philips 17" LCD). After the presentation of the string of digits there was a 1 second delay, following which the participants entered the sequence of numbers using the number pad on the computer's keyboard. Participants pressed the enter key when they were ready to input the number sequence they had entered. The performance measure considered was the recall success rate (percentage correct) of the five and seven digit strings (Goble, 2013). The tests for both difficulties were broken up into three sets of two trials each. Each trial lasted approximately 30 seconds but this was dependent on the participants' response time.

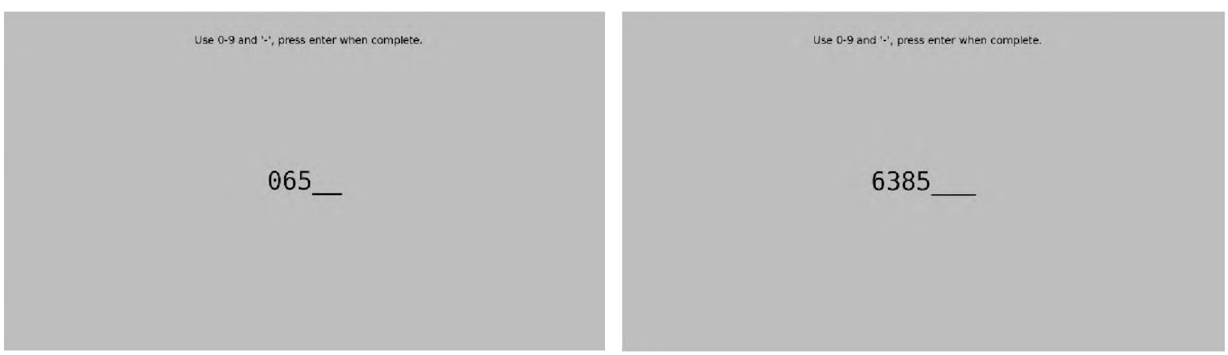
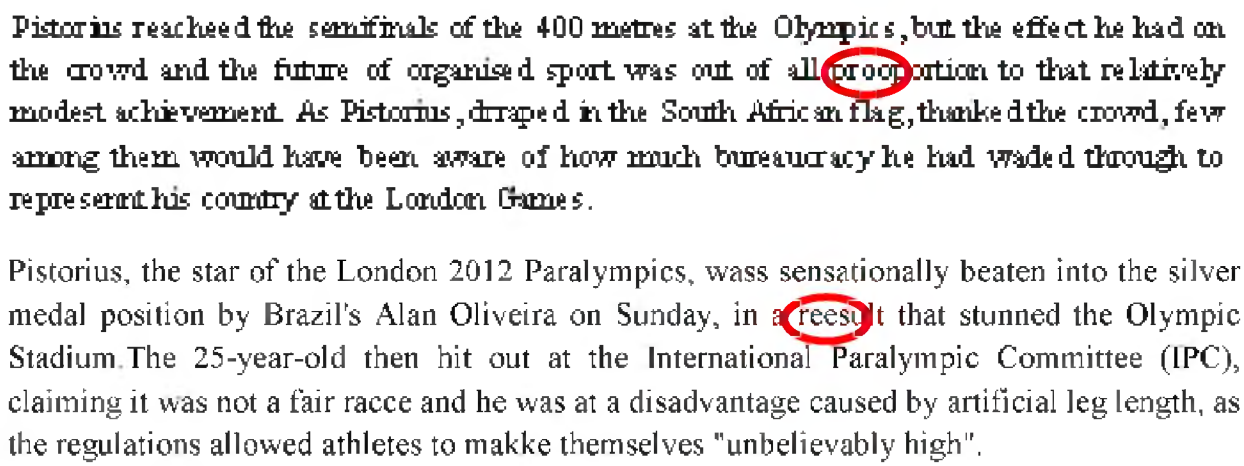


Figure 5: PEBL memory task (left: low difficulty - 5 digits, right: high difficulty - 7 digits).

3.4.4 Recognition

The recognition test was a proof reading task in which the participants read two paragraphs of writing in which they had to identify errors in spelling. These errors took the form of double letters in words where these were incorrect (Tichiwanhuyi, 2015). A proof reading task was chosen as it tests object recognition (Goble, 2013). The errors in spelling were placed to average one in every 20 words, amounting to 5 errors in every 100 words.

The text to be read was typed in Times New Roman 12pt with 1.15 line spacing. There were two reading conditions in the test, low and high resolution (Figure 6). The performance measures in this study were the error detection rate and reading speed (words/minute). The duration of this test was 90 seconds, split into three 30 second sessions, for each of the resolution levels.



Pistorius reacheed the semifinals of the 400 metres at the Olympics, but the effect he had on the crowd and the future of organised sport was out of all prooportion to that relatively modest achievement. As Pistorius, draped in the South African flag, thanked the crowd, few among them would have been aware of how much bureaucracy he had waded through to represent his country at the London Games.

Pistorius, the star of the London 2012 Paralympics, wass sensationally beaten into the silver medal position by Brazil's Alan Oliveira on Sunday, in a reesult that stunned the Olympic Stadium. The 25-year-old then hit out at the International Paralympic Committee (IPC), claiming it was not a fair racce and he was at a disadvantage caused by artificial leg length, as the regulations allowed athletes to makke themselves "unbelievably high".

Figure 6: Recognition (proof reading) task (Top: High difficulty - low resolution, Bottom: Low difficulty - high resolution). The red circles are highlighting examples of the errors in the text.

3.4.5 Tracking task

A low fidelity driving simulator was used as the simple tracking task. The driving simulator task was chosen as it tests the participant's motor control. The task involved participants' performing a simple line tracking task. Participants were required to use a two dimensional driving simulator and keep the point of a triangle tracking along a white line against a grey background (Figure 7). The speed was set at a constant 5 $km.h^{-1}$ (Sunshine, 2013). The participants kept the point of the triangle on the line by tracking left and right using the arrow keys on the computers keyboard. The simulator test was performed on a Philips 17" LCD computer screen. Performance was measured using deviation from the line as well as the amplitude and frequency of the deviation. The duration of this test was 60 seconds (Goble, 2013), split into two 30 second sessions.

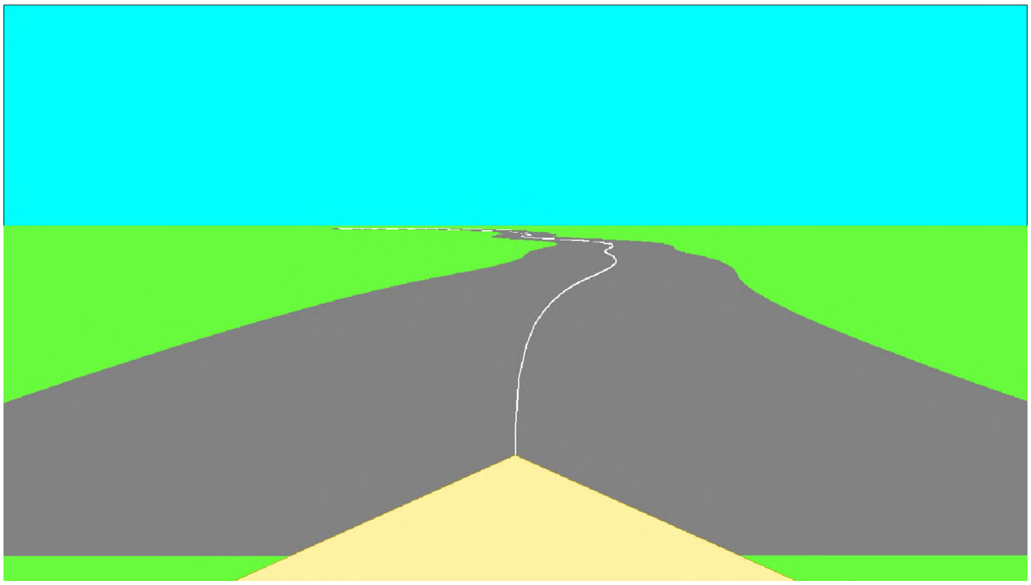


Figure 7: Low fidelity driving simulator.

3.5 Controlled variables

The light conditions, water clarity and water temperature in the hydrostatic weighing tank were controlled for the duration of the study. Water temperature was maintained at constant 30 degrees Celsius (°C) to avoid the influence of cold water as a stressor on cognitive performance (Patil et al., 1995). Water clarity was maintained to negate any influence of altered stereoscopic acuity (Luria & Kinney, 1968).

3.6 Participants

Participants were gathered from the wider Grahamstown area as well as from the Rhodes University staff and student population, preferably, but not limited to, members of the Rhodes University Underwater Club.

3.6.1 Inclusion

Email and social media posts (Facebook posts) were used to advertise the study and attract the attention of volunteers.

The age range of 18-45 was chosen in order to get the largest testing population possible for the study and no literature was found that indicated the general age range of occupational divers.

It is acknowledged that the large age range might increase the variance in cognitive performance. However, due to the fact that the sample of experienced divers was limited and that the study employed a within participant design this compromise was deemed acceptable.

Participants were required to have a minimum of six months regular (minimum of once a month) underwater experience; partaking in either scuba diving, underwater hockey, spearfishing or water based training. The above mentioned activities were used as they allude to a level of comfort in water that may not necessarily be present in people who do not participate in those activities. Participants were additionally required to be able to maintain a consistent 30 second apnea underwater, with the apnea being repeated 20 times in 20 to 30 minutes. Participants without underwater experience were considered only if they were able to perform the repeated 30 second apnea sessions underwater. The 30 second consistent repeated apnea test was used to ensure that the participants were able to participate in all the conditions of the testing as one condition involved repeated 30 second apneas underwater.

3.6.2 Exclusion

Participants that were not physically active, did not engage in regular underwater sport, could not swim or did not meet the inclusion criteria were excluded from the study. All participants were asked to avoid all caffeinated and alcoholic drinks for 24 hours prior to the testing, refrain from smoking 3 hours before testing and to avoid eating a heavy meal immediately prior to testing. Any participants who failed to do so were rescheduled for testing at another time provided they had refrained from the above at that time. This exclusion was included as both caffeine and alcohol have an impact on cognitive functioning which may impact on the results of this study (Lorist & Snel, 1997; Schweizer, Vogel-Sprott, Dixon, & Jolicoeur, 2005). Participants were requested to refrain from smoking as it has an impact on lung functioning which may have an impact on their ability to maintain an apnea and could potentially have put them at risk (Willemse, Postma, Timens, & ten Hacken, 2004). Participants were requested to avoid heavy meals immediately prior to the testing as it may cause personal discomfort which may have in turn affected the results of the study. Any participants who felt claustrophobic during the information and habituation session were excluded from the study. Participants who may have met the inclusion criteria but had suffered any form of respiratory disease in the past three months were excluded from the study.

3.7 Testing setup

The testing conditions were setup in a hydrostatic weighing tank with a depth of 2 metres. Testing in the hydrostatic weighing tank was chosen as it allowed for light conditions, water clarity and water temperature to be controlled throughout the testing. Participants were seated at a chair and table setup at the bottom of the hydrostatic weighing tank for the testing sessions and were seated at an identical set up for the on land session. All the information processing tasks were conducted on a computer, with the exception of the proof reading task which was on laminated paper. For all of the computer based tasks the participants used a waterproof computer keyboard to perform any of the required actions during the tests. The same computer and keyboard were used for both the underwater conditions and the on land condition. The testing setup in the tank allowed the participants to be seated underwater while still being able to work on a computer; the screen of which was mounted against the glass of the hydrostatic weighing tank. The use of an underwater testing setup required the use of equipment capable of operating underwater. This required the equipment to be both waterproof and pressure resistant. This issue was easily overcome for the computer screen as the hydrostatic weighing tanks glass window allowed for the screen to remain out of the water but still be viewable from inside the tank. The keyboard used was waterproof by design but when subjected to pressure, both the keys and mouse trackpad became unusable. This issue was overcome in two steps: 1) The keyboard was pressurised to allow the keys to reset after being pressed and 2) The need to use trackpad was removed by adapting the tracking task to use the arrow keys on the keyboard.

3.7.1 Test setup

A plastic table was used as the testing platform for all three conditions (see Figure 10 for the underwater test station setup). A plastic chair weighted to sit on the bottom of the hydrostatic weighing tank was used as seating for the participants in the underwater conditions and an identical unweighted chair was used during the on land condition. The underwater testing setup can be seen in Figure 8. A weight belt was provided for the participants to weigh themselves down into the chair during the testing session. The weight of the belt was calculated as four to six percent of the participant's body mass on land prior to submersion (as assessed using a body scale during habituation). During scuba diving a weight of ten percent of the divers body mass is used on the weight belt, according to www.scubadiving.com (Brumm, 2013). This website was used as there was no direct source relating to the amount of weight generally required for scuba diving or spearfishing. This figure, of ten percent of the divers' body mass, has been corroborated through consultation with highly experienced scuba divers and spear fishermen. Through these consultations it was established that four to six percent of a participants' body mass would be sufficient to keep them in the seat and prevent them from floating up involuntarily. This was confirmed by the researcher through trials with different weights in the underwater test setup. The range of four to six percent was used to account for differences that may exist between participants' body compositions. This weight allowed the participants to be comfortably weighted down enough that they did not float up during the testing but was not too heavy preventing them from being able to surface whenever necessary. The weight belt buckle was a quick release buckle and as such the participants could easily remove the belt if they wished to surface rapidly. Scuba gear in the form of an air tank and respirator was in the hydrostatic weight tank to be used by the participant in the assisted breathing condition.

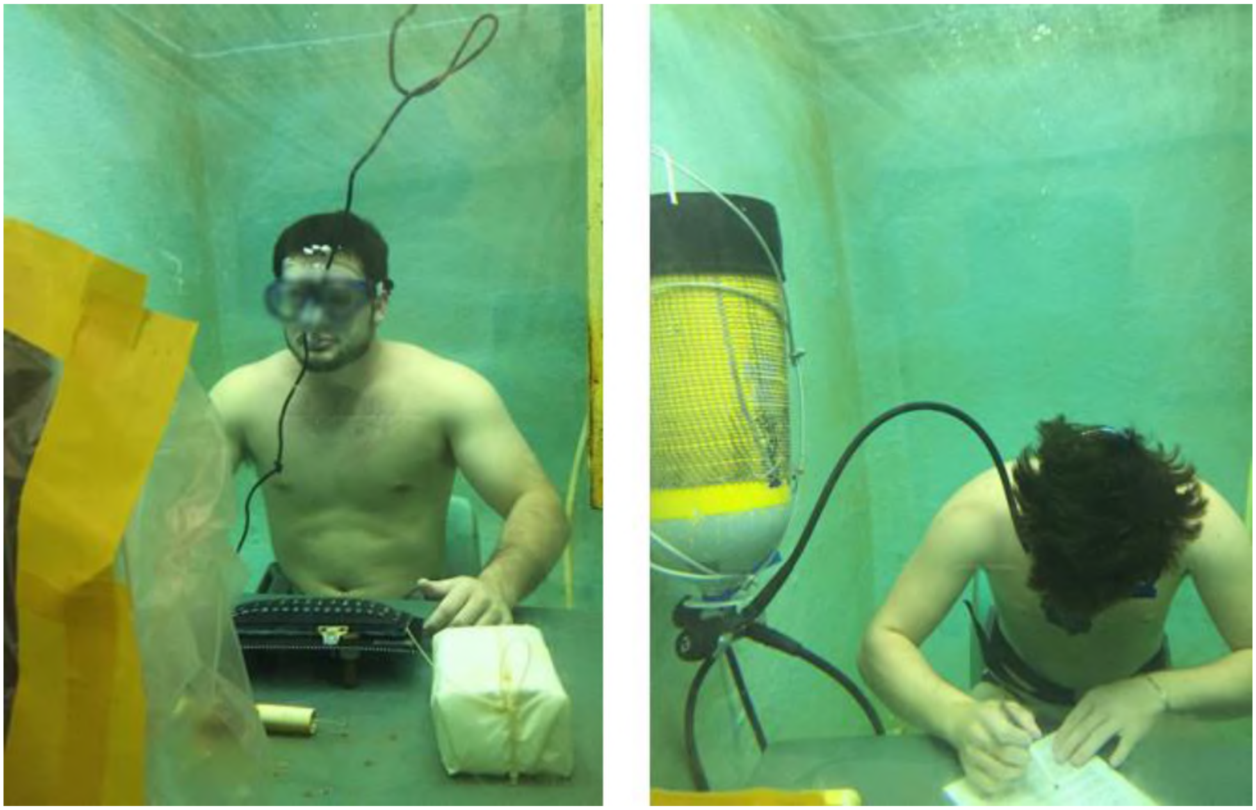


Figure 8: The underwater test setup from the researchers view. Right: A participant in the assisted breathing condition - recognition task. Left: A participant in the apnea condition - computer based task.

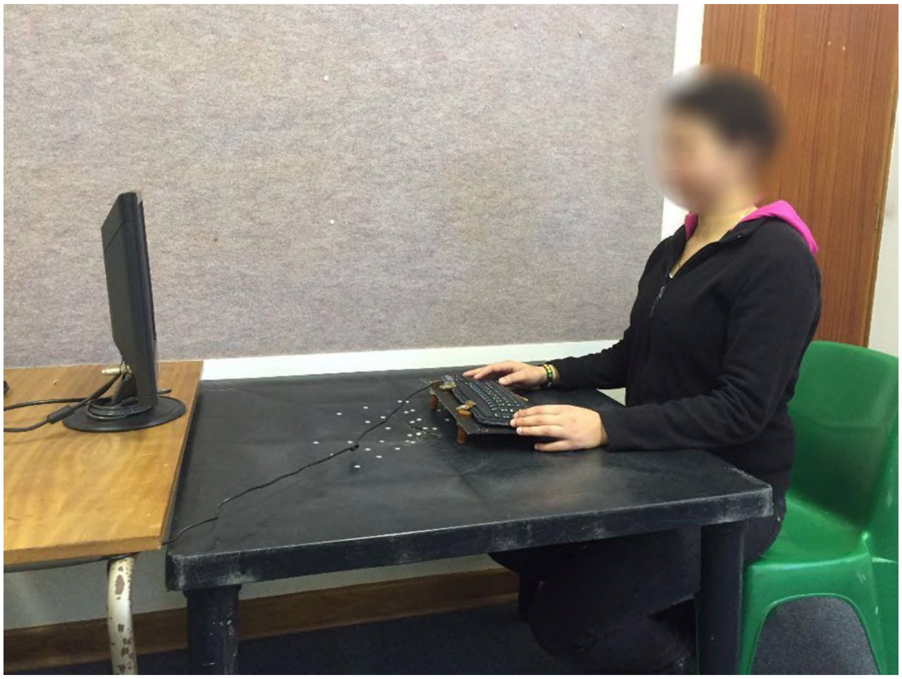


Figure 9: Lateral view of the land condition setup.

The researcher's perspective of the test setup is shown in Figure 8. The cover of the computer screen can be seen on the left hand side of the right hand image. Figure 9 shows the land condition setup with the keyboard and screen. The table, chair and screen are the same as the ones used in the underwater setup and the keyboard is the exact same one moved between the two setups. The distance between the participant and the computer screen seen in Figure 9 is the same as the underwater setup.

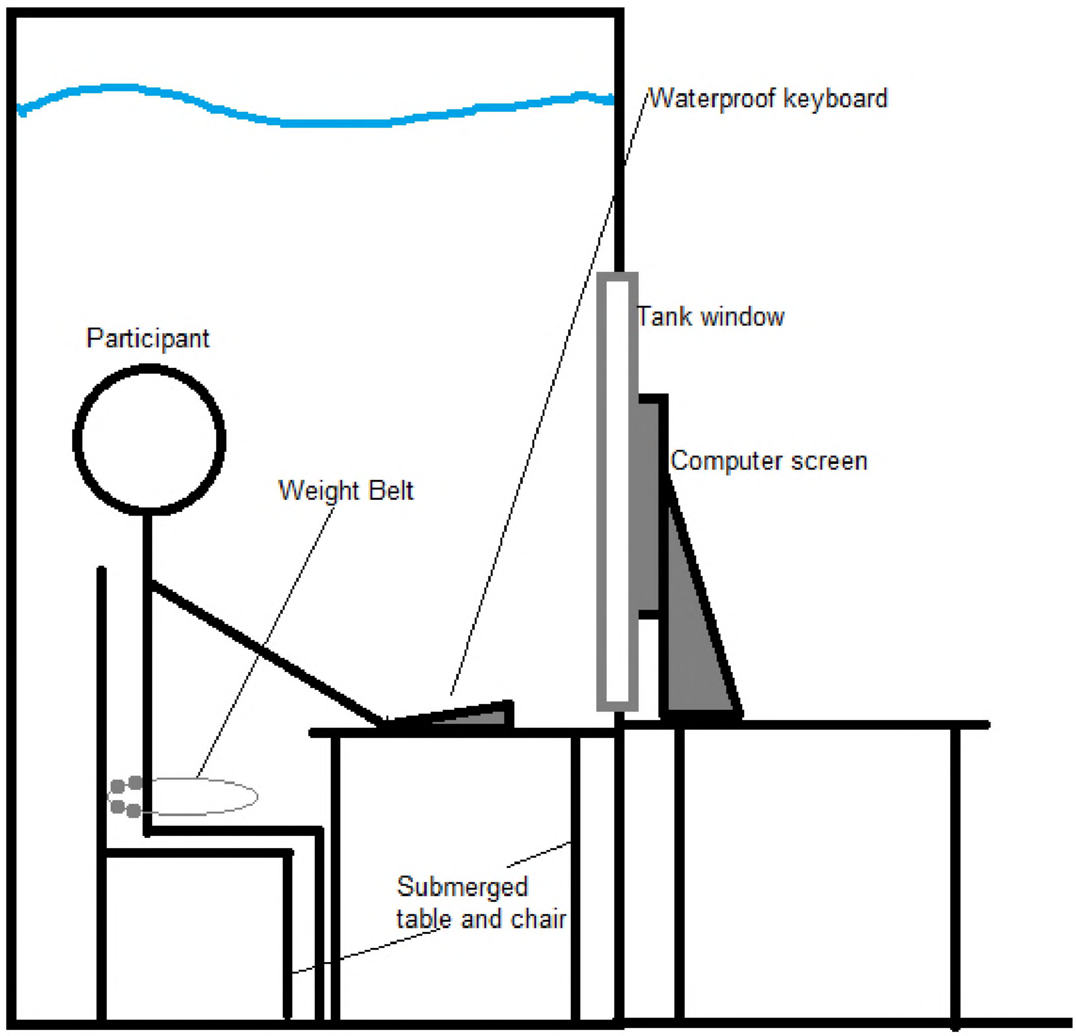


Figure 10: An annotated lateral view of the underwater test station setup.

3.7.2 Permutation

The order of the conditions was permutated between the participants (Table IX in Appendix A5). The permutation table was constructed to randomise the order in which the participants were tested in the various conditions. A permutation was also made for the order in which the tasks were conducted within each condition (Table X in Appendix A5).

3.7.3 Test battery setup

The information processing test battery was used in all three conditions, with all the same tests being used in a permutated order. All the tests conducted on a computer used the computer keyboard. For the underwater conditions the keyboard was underwater on the testing platform for the participant to use. The computer screen was mounted on the outside of the glass window of the hydrostatic weighing tank for the participants to be able to see the various tests. During the on land condition the keyboard was the same as for the underwater conditions. The computer monitor was also positioned the same distance away from the participants as it was in the underwater conditions.

3.8 Experimental procedure

Testing was conducted in four sessions; habituation and information, on land and two underwater sessions. As such participants were required to come to the Human Kinetics and Ergonomics Department (HKE), Rhodes University four times.

3.8.1 Test battery duration

The duration of the test battery was approximately 15 minutes, allowing for switching between the tests and preparation time. The five independent tests each had varying durations (see Table I). The times displayed below were the total test times. Tests were broken up into thirty second sessions to accommodate the apnea condition.

Table I: Test battery and task durations.

Task	Simple task duration (seconds)	Difficult task duration (seconds)
Visual Detection	60	60
Reaction Time	30	30
Memory	90	90
Recognition	90	90
Tracking	60	N/A
Duration (minutes)	5.5	4.5
Total duration (minutes)	10	

The task that required the most time was the recognition task (Proof reading task), with a duration of 90 seconds. The shortest task was the reaction time task, lasting 30 seconds. In order to facilitate the change over from task to task 15 minutes was allocated to the test battery. The test battery was conducted in a permutated order in each of the testing sessions.

3.8.2 Information and habituation session

All testing was conducted in the Human Kinetics and Ergonomics (HKE) hydrostatic weighing tank, for the two underwater conditions, and isokinetic dynamometry room, for the on land conditions, where identical testing stations were set up for all data collection procedures. During the habituation and information session the researcher fully explained all the procedures involved in the testing to the participant and answered all questions the participant had. The participant signed an informed consent form to show they fully understood their participation and also gave permission for the use of their data in the study. The participant was then weighed to determine the amount of weight that was required on the weight belt for the habituation trials in the tank and the actual testing. The researcher then allowed the participant to seat themselves at each of the testing stations to ensure they were comfortable in all the conditions. The participant was given the opportunity to enter the tank and use all of the equipment involved in the testing as well as conduct repeated 30 second apneas and breathe underwater using the breathing apparatus. This time underwater in the tank allowed the participant to determine their level of comfort in the test setup and withdraw if they felt they were not comfortable in the setup.

3.8.3 Underwater with assisted breathing

In this session the participant was given time to become accustomed to the water, the breathing apparatus and being underwater. Once the participant was comfortable with the setup they were briefed on the procedure by the researcher. After the briefing the participant put on the weight belt, sat in the chair at the testing station and breathed calmly through the regulator. Once the participant was seated and breathing normally they started the various information processing tests. The tests were conducted in a permutated order and the participant surfaced between tests.

3.8.4 Underwater with apnea

In this session the participant was given time to become accustomed to the water, holding their breath and being underwater. Once the participant was comfortable with the setup they were briefed on the procedure by the researcher. After being briefed the participant put on the weight belt and was given time to become accustomed to being in the seat, holding their breath and being weighed down. Once the participant was ready they sunk down onto the chair and performed the various information processing tasks in thirty second sessions. All the tasks were conducted in a permutated order and the participant surfaced between sessions. All the tests were limited to thirty second sessions to allow the participant to perform the test before running out of air.

3.8.5 On land

In this session the participant was briefed on the procedures by the researcher. The participant was then seated at the testing station where they performed the information processing tasks in a permutated order.

3.9 Data reduction and analysis

All cognitive performance data was extracted from the PEBL software, Stimulus-response software and records of the proof reading task. The data was then summarised in Microsoft Excel spreadsheets as tables. All the data was then imported into STATISTICA (version 13) data analysis software where an analysis of variance (ANOVA) was run for all of the tests across the three testing conditions to check for statistical significance. A Tukey Post-Hoc analysis was conducted on any data where a statistical significance was found. The three testing conditions were on land, underwater with assisted breathing and underwater with apnea.

4 Results

4.1 Introduction

This chapter presents the data collected from the experimental procedure designed to assess the effect of submersion in water and breathing modality on different stages of the information processing chain. Participants completed five tasks in three conditions. Four of the tasks consisted of a high and low difficulty variation of the task. The data presented is of all five tasks, with varying measures within each task.

The data is the combined responses of all participants in the study (n=18). All data was analysed in STATISTICA software using a repeated measures analysis of variance (ANOVA), and if any statistical significances were found a Tukey post hoc test was conducted. Data was displayed using STATISTICA software graphing the data as means with standard deviation (SD) error bars.

Significances relating to difficulty were expected as increasing the difficulty of a task will likely result in a difference in performance between the low and high difficulties of the task. Condition effects are the main interest of the research. As such the main focus will be on the presence and possible cause of any condition effects found. The results displayed will be broken down into the different aspects of each task that was measured.

4.2 Participant characteristics

14 males and 4 females, with a mean age of 25.3 years, were recruited and tested through the course of the study. All participants had a minimum of six months underwater experience in either underwater hockey, spearfishing, scuba diving or water based training, for sports such as water polo. Participants' length of experience underwater ranged from one to 30 years ($\bar{x}$ = 7.56 years). All participants were capable of performing a consistent and repeated 30 second apnea underwater.

4.3 Results overview

Table II: Overview of the results of the different tasks in the study showing significance for condition, difficulty and repetition.

Task	Apnea	Assisted	Land
Reaction Time			
Recognition – Accuracy			*
Recognition – Speed		*	
Memory – Speed			*
Memory – Accuracy			
Visual Detection – Speed			*
Visual Detection – Accuracy			*
Visual Detection – Eccentricity Response Time			
Tracking – Mean Deviation			

*Red highlight indicates statistical significance, $p<0.05$, and the conditions it was found between. Asterisk * indicates which condition performance was significantly better.*

Table II indicates the tasks and speed or accuracy aspects, where a significant effect of condition was found, which conditions the effect was found between, and which condition had the better performance. A Tukey post hoc analysis was used to determine which conditions the effect was found between (Appendix D).

4.4 Reaction time

The reaction time task required the participants to respond to the presentation of stimuli on a computer screen, clicking the appropriate mouse button when the corresponding stimuli appeared on the screen. There were two levels of difficulty in the task, the high difficulty involving two stimuli and the low difficulty consisting of only one.

Table III shows the repeated measures ANOVA for the reaction time data for both high and low difficulty across the three conditions of the testing. Statistical significance was found for both difficulty and repetition, while no effect was found for condition.

Table III: Repeated measures analysis of variance of reaction time.

Effect	Degree of Freedom	F	P
CONDITION	2, 34	2.345	0.111
DIFFICULTY	1, 17	310.866	<0.01*
REPETITION	21, 357	2.339	<0.01*
CONDITION *DIFFICULTY	2, 34	0.857	0.434
CONDITION*REPETITION	42, 714	0.984	0.501
DIFFICULTY*REPETITION	21, 357	1.459	0.088
CONDITION*DIFFICULTY*REPETITION	42, 714	0.990	0.492

Asterisk highlights statistical significance*

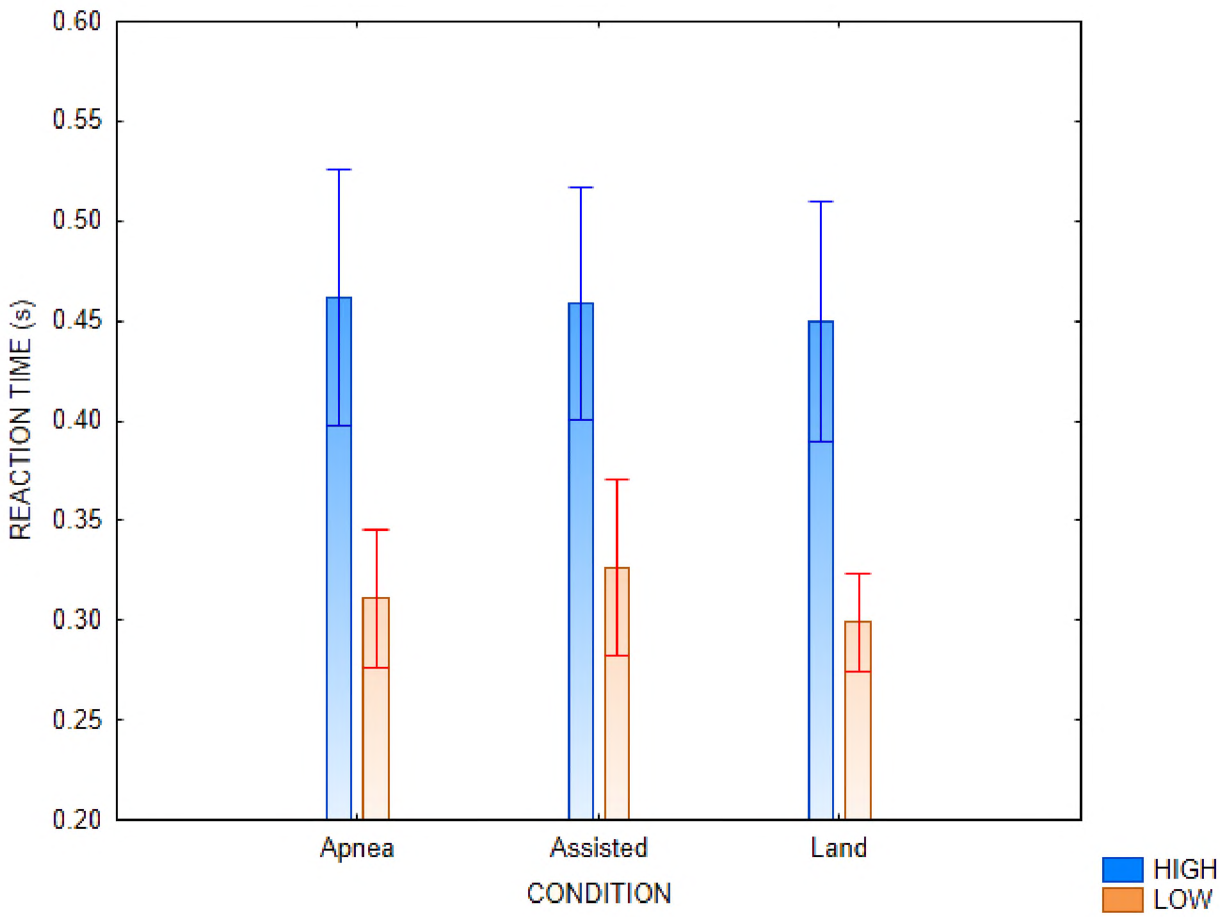


Figure 11: Mean (±SD) reaction time result for the three conditions of the study across both difficulties.

Figure 11 shows the similarity in the reaction times over the three conditions with the responses in the land condition having a slightly quicker average reaction time for both difficulties. An increase in response time for the lower difficulty of the task was evident in the assisted breathing condition compared to the other two, which is not seen for the high difficulty task. There was no significant difference found between the three conditions. However, there was a significant increase in reaction time across the duration of the task, indicating that there was a deterioration in performance over time (Figure 20 in Appendix B2).

4.5 Recognition

The recognition task consisted of two levels of difficulty, attributed to different resolutions of text, with low resolution text being high difficulty and high resolution being low difficulty. The recognition task data was split into errors detected, number of words read and reading speed.

4.5.1 Errors detected

Table IV shows the repeated measures ANOVA for the percentage of errors detected in the recognition task for the three conditions, across both high and low difficulties. Statistical significance was found for both condition and difficulty. The significance found for condition was between the on land and assisted breathing conditions. The apnea condition was not significantly different to either the assisted breathing or land conditions.

Table IV: Repeated measures analysis of variance of errors detected in the recognition task.

Effect	Degree of Freedom	F	P
CONDITION	2, 34	5.114	0.012
DIFFICULTY	1, 17	12.931	<0.01*
CONDITION*DIFFICULTY	2, 34	0.090	0.914

Asterisk highlights statistical significance*

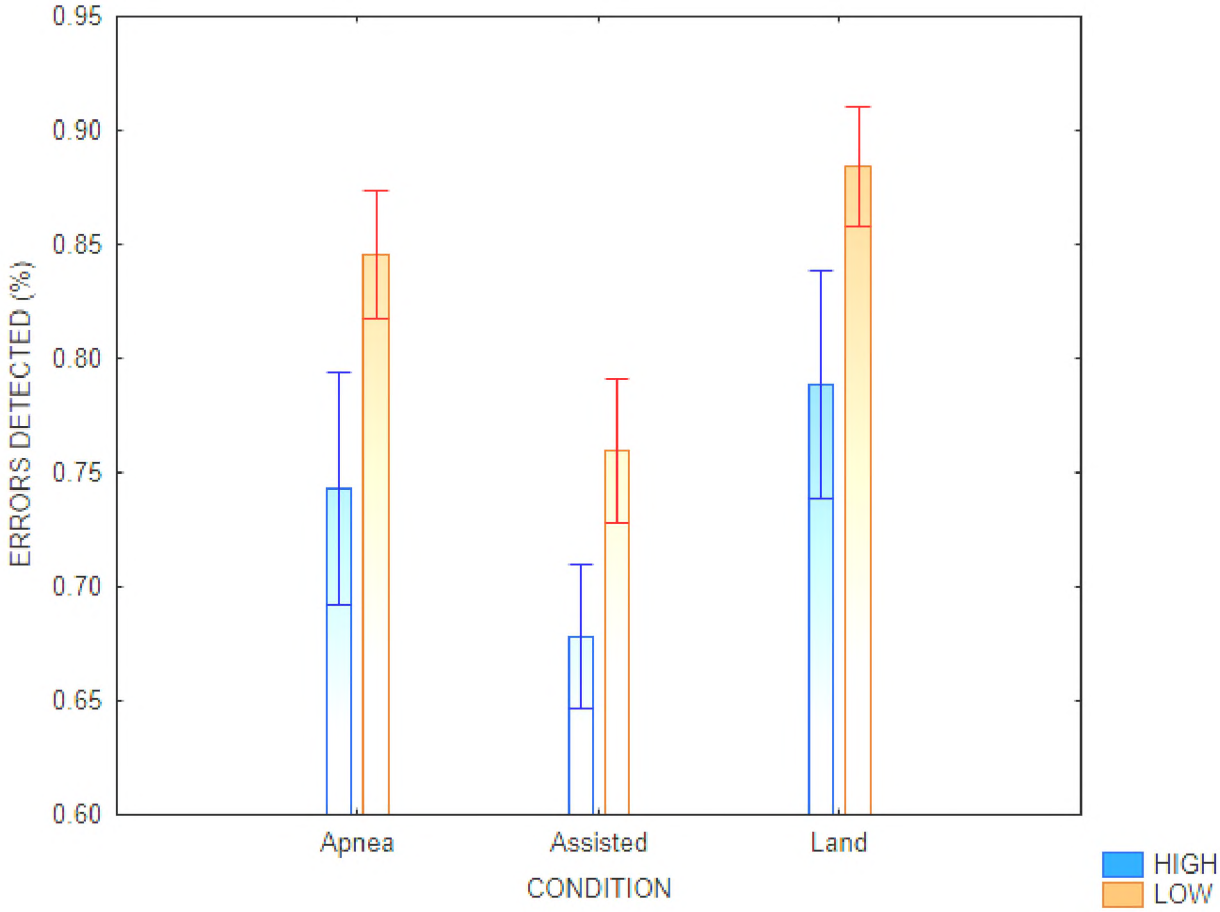


Figure 12: Recognition task (proof reading), mean (±SD) number of errors detected across the three conditions for both difficulties.

Figure 12 shows the percentage errors detected across the three conditions for both difficulties. Both difficulties follow similar trends for the three conditions. The graph indicates that the performance in the assisted breathing condition was the worst of the three conditions. The decrement in performance between the assisted breathing condition and the other two conditions was evident for both levels of difficulty. This is confirmed by the ANOVA ($p = 0.012$) and post hoc tests (Table XXXVIII in Appendix D3).

This significant difference for condition was also found for the number of words read and reading speed. These two variables were expected to have the same result as reading speed is calculated using the number of words read and the reading time was kept constant. As a result of this relationship, the results found were the same. The data followed the inverse of the trend shown in Figure 12 with the assisted breathing condition having the highest number of words read and the fastest reading speed. The reading speed and number of words read in the assisted breathing was significantly higher than the land condition (p = 0.042). This was confirmed by the post hoc test (Table XXXIX in Appendix D3).

This result shows that the assisted breathing condition resulted in a significantly lower performance in accuracy (percentage of errors detected), with a significantly higher performance in the speed aspect of the task (words read and reading speed) (Figure 22 and Figure 23in Appendix B4). This results shows the speed-accuracy trade off and indicates that the use of the assisted breathing was the cause of the increase in speed and decrease in accuracy. The submersion aspect of the condition did not have a significant effect as the apnea condition was not significantly different to either of the other conditions.

4.6 Memory recall

The memory recall task was performed on the PEBL software and consisted of the participants viewing a string of either five or seven digits, low and high difficulty respectively, and inputting the string back into the computer after a short pause. The data was analysed in the form of response time to the stimuli and the percentage of correct responses across the three conditions.

4.6.1 Response time

The repeated measures ANOVA for response time in the memory recall task displayed in Table V shows statistical significances were found for condition, difficulty and repetition. The condition effect was found to be between the land and apnea condition, using a post hoc analysis (Table XXXVII in Appendix D2).

Table V: Repeated measures analysis of variance of response time for the memory recall task.

Effect	Degree of Freedom	F	P
CONDITION	2, 34	4.462	0.019*
DIFFICULTY	1, 17	66.473	<0.01*
REPETITION	5, 85	2.688	0.026*
CONDITION*DIFFICULTY	2, 34	2.094	0.139
CONDITION*REPETITION	10, 170	0.711	0.714
DIFFICULTY*REPETITION	5, 85	3.748	<0.01*
CONDITION*DIFFICULTY*REPETITION	10, 170	1.196	0.297

Asterisk highlights statistical significance*

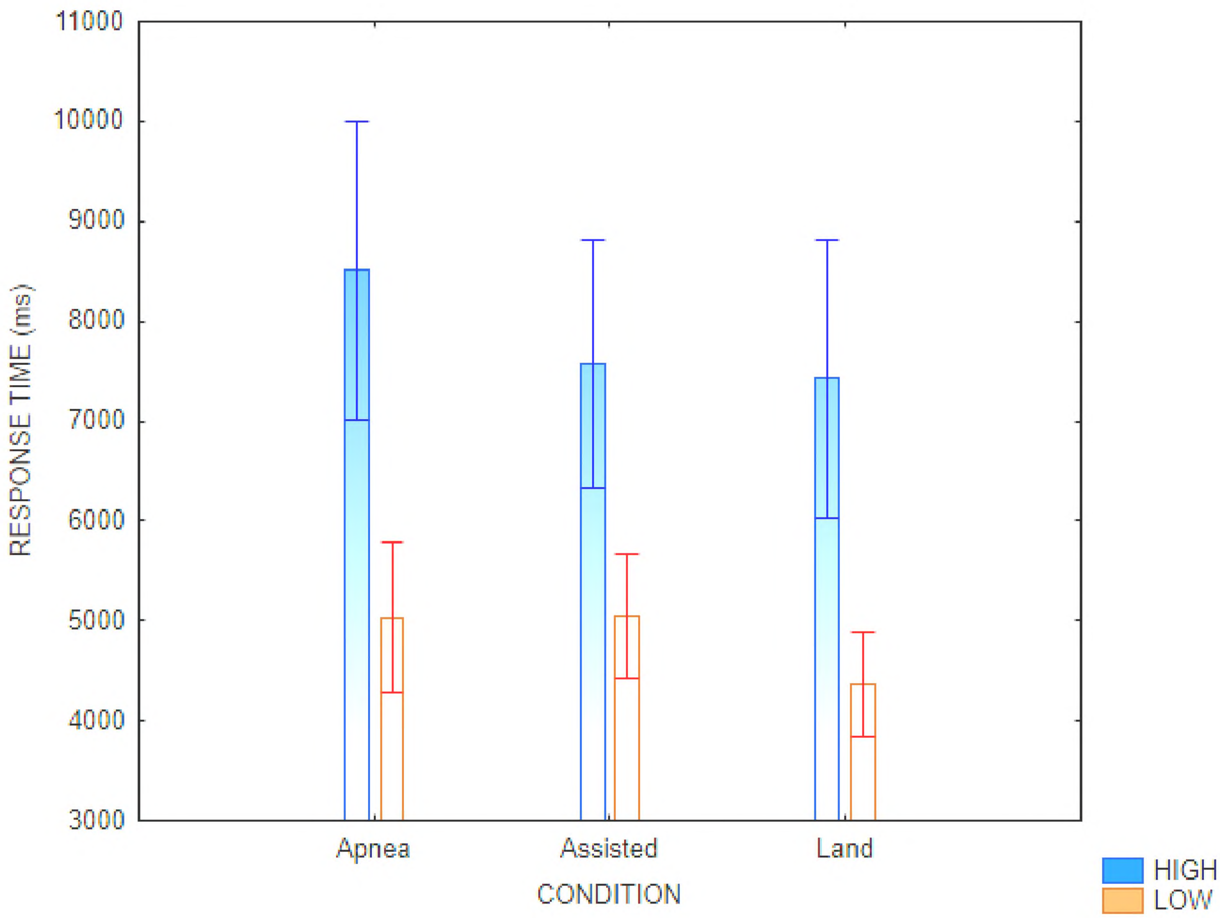


Figure 13: Memory task mean (±SD) response times across the three conditions for both difficulties.

Figure 13 shows the response times in the apnea condition are slower than the land condition, and the difference in mean response times are higher for the high difficulty. This increase for the high difficulty is explained by the longer string of digits used in the high difficulty in comparison to the low difficulty, which require more time to input. The significant difference between the land and apnea condition was confirmed by the post hoc analysis (Table XXXVII in Appendix D2). This finding indicates that the apnea aspect of the underwater condition was the factor that lead to the poorer response times as the assisted breathing response times were not significantly different to the apnea or land times. There was an effect found for repetition ($p=0.026$) with the response time decreasing from start to end of the task across all conditions (Figure 21 in Appendix B3).

The change in response time indicates a learning/habituation effect to the task as it progressed.

4.6.2 Percent correct responses

The percent correct responses was determined by calculating the total number of correct responses over the entire task duration; two strings of digits over three sessions resulting in a total of six repetitions, for each participant. Table VI shows the repeated measures ANOVA for the percent of correct responses in the memory recall task for the three conditions and both difficulties. Statistical significance was found for difficulty. This result was expected as the increase from five digits to seven was assumed to result in a reduction in the number of correct responses as the more items there are to remember the higher the rate of memory decay (Figure 3). There was no statistical significance found for condition.

Table VI: Repeated measures analysis of variance of percent correct responses for the memory recall task.

Effect	Degree of Freedom	F	P
CONDITION	2, 34	1.020	0.371
DIFFICULTY	1, 17	56.972	<0.01*
CONDITION*DIFFICULTY	2, 34	0.614	0.547

Asterisk highlights statistical significance*

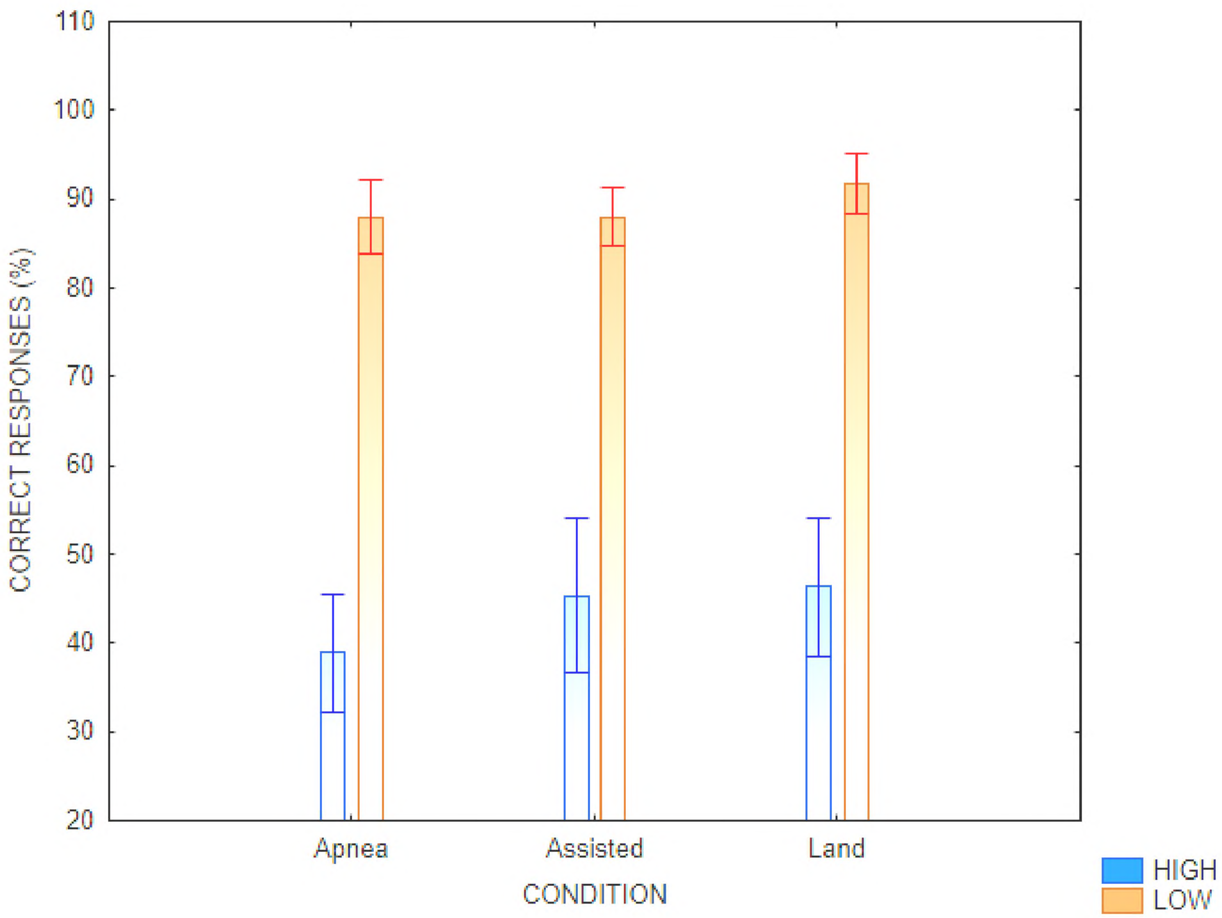


Figure 14: Mean (±SD) percent correct responses in the memory task across the three conditions for both difficulties.

Figure 14 shows the percentage of correct responses for the memory recall task did not differ significantly much between the conditions. When viewed alongside Figure 13, Figure 14 shows that the longer response times resulted in a slightly poorer performance which could possibly be linked to the decay rate of memory. The longer the time between input of a stimuli and the point where it is recited or outputted. Figure 14 displays the effect of difficulty in the task with the more difficult task having a significantly lower percentage of correct responses across all three conditions. This difference between the two difficulties is like due to the rate of memory decay increasing with the more items that must be remembered (Figure 3).

There being no significant effect of condition on the percentage of correct responses, but there being one for response time indicates that the apnea condition reduced the performance of the task with regards to speed, but it did not impact on the accuracy of the participants.

4.7 Visual detection

The visual detection task took the form of a series of stimuli moving outwards on the screen, requiring the participant to click when the critical stimuli appeared on the screen. The data was analysed in the form of response time, percent of overlooked stimuli and number of stimuli detected.

4.7.1 Response time

Table VII shows the repeated measures ANOVA for response time in the visual detection task. There was a statistical significance found for condition, specifically between the land condition and both underwater conditions.

Table VII: Repeated measures analysis of variance of response time for the visual detection task.

Effect	Degree of Freedom	F	P
CONDITION	2, 34	17.594	<0.01*
DIFFICULTY	1, 17	2.985	0.102
REPETITION	1, 17	1.239	0.281
CONDITION*DIFFICULTY	2, 34	1.129	0.335
CONDITION*REPETITION	2, 34	2.563	0.092
DIFFICULTY*REPETITION	1, 17	0.305	0.588
CONDITION*DIFFICULTY*REPETITION	2, 34	1.005	0.377

Asterisk highlights statistical significance*

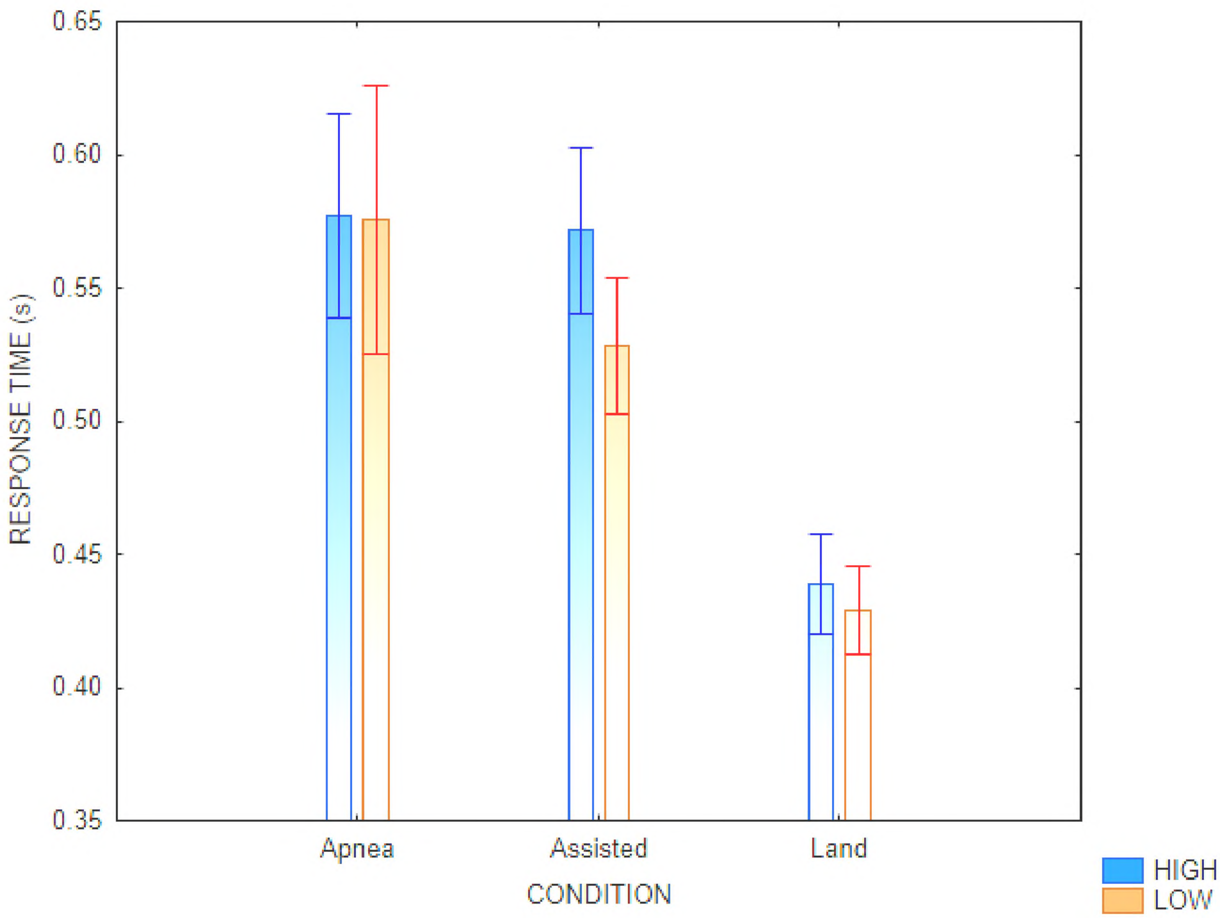


Figure 15: Visual detection task mean (±SD) response time to stimuli across the three conditions for both difficulties.

Visual detection task response times were similar between the two underwater conditions and both were considerably slower than the land condition. The participants' responses show less variance moving from the apnea to assisted breathing and land conditions for both difficulties. This may indicate that the apnea condition resulted in some participants finding it relatively easy to function in. Whereas the land condition was the easiest for all participants to function in, this may be a result of experience, of lack thereof, in the condition.

The percentage overlooked stimuli and number of stimuli detected were the accuracy measures for this task. The two measures were linked and would be in inverse of each other as the more stimuli one detects the less there will be to be overlooked. The percent of stimuli overlooked followed the same trend as the response time, with significantly less overlooked stimuli in the land condition (Figure 17 in Appendix B1). This was confirmed by the post hoc test (Table XXXIV in Appendix D1). The number of stimuli detected followed the opposite trend with the highest number of stimuli detected in the land condition (Figure 19 in Appendix B1). The land condition had the best performance in both the speed and accuracy components of this task with quicker response times, less stimuli overlooked and more stimuli detected.

For all aspects of this task, both underwater conditions had significantly poorer performances compared to the land condition (Appendix D1). The consistent difference in both speed and accuracy between the land condition and both underwater conditions indicates that there was a common aspect between both underwater conditions that resulted in reduced performances in the task. The commonality between the two underwater conditions was the submersion in water as the only differences in the conditions was the breathing modality. Therefore the reduction in performance must be attributed to the submersion in water.

4.7.2 The effect of eccentricity

The effect of eccentricity, the position of the critical stimuli relative to the centre of the computer screen, on response time was looked at to investigate whether position on the screen had an impact on the response time to the stimuli. This was done by comparing response times to stimuli in two eccentricities of the task, the middle region of the screen (0-3.93º) or the first outer band (3.93-7.87º). There was no effect of eccentricity found (Please refer to Table XIII, Appendix B1 and Figure 18, Appendix B1 for more details).

4.8 Tracking

The tracking task was a low fidelity driving simulator that required the participant to keep the tip of a triangle tracking along the centre line using the arrow keys on the keyboard. The data was in the form of mean deviation from the centre line.

4.8.1 Mean deviation

Table VIII shows the repeated measures ANOVA for the tracking task. No significant differences in the mean deviation were found across the three conditions.

Table VIII: Repeated measures analysis of variance for the mean deviation in the tracking task.

Effect	Degree of Freedom	F	P
CONDITION	2, 34	2.158	0.131
REPETITION	1, 17	3.009	0.101
CONDITION*REPETITION	2, 34	0.489	0.618

Asterisk highlights statistical significance*

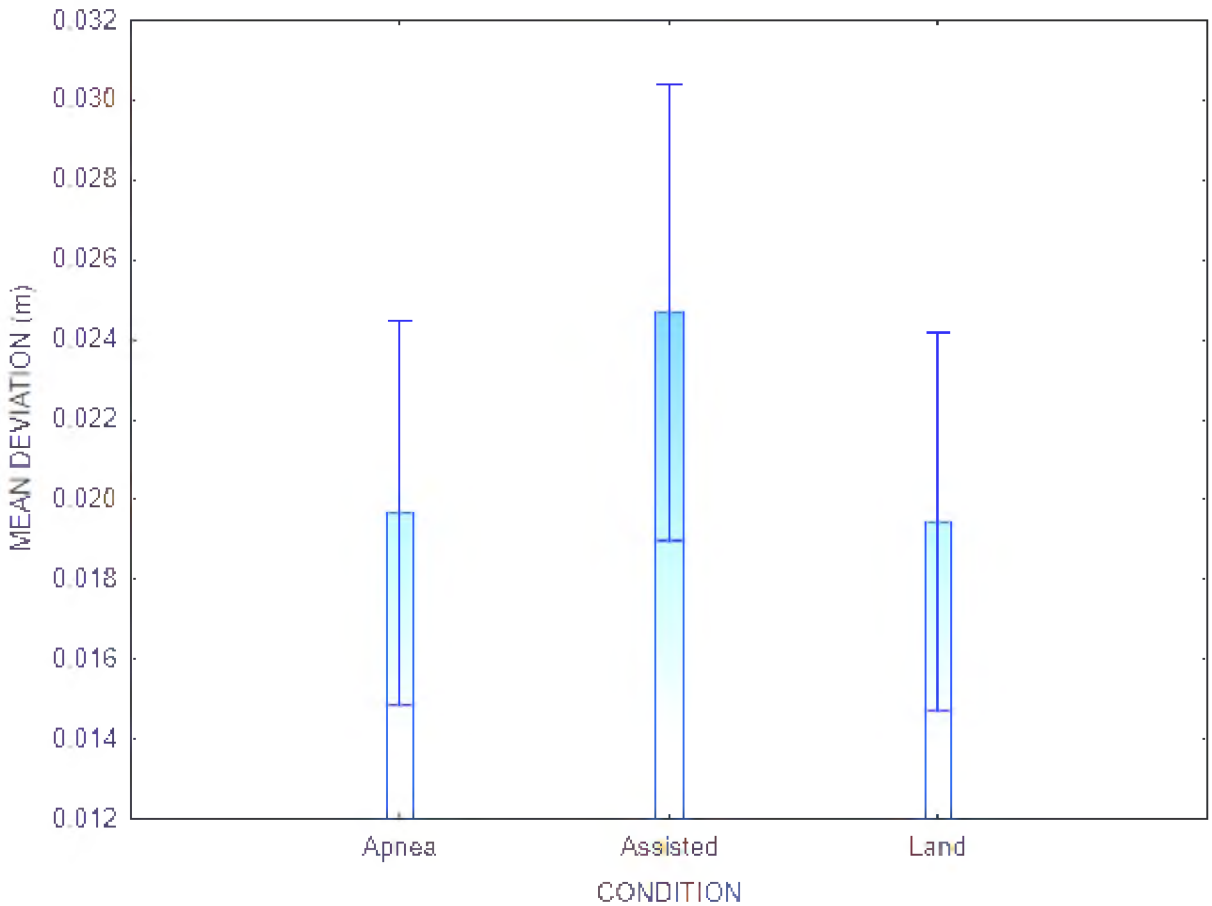


Figure 16: Tracking task, mean (±SD) deviation from the centre line across the three conditions.

The Tracking results show that there was a greater deviation from the centre line in the assisted breathing condition, however this difference was not significant. The variation within the data was relatively uniform across the three conditions.

4.9 Effect of experience

Years of experience underwater was analysed as a continuous predictor in a repeated measures analysis of variance for each of the data sets above. Years of experience was found to have a significant effect for the tracking task ($p<0.01$), number of stimuli detected and eccentric response time of the visual detection task ($p<0.05$) and with repetition in the reaction time task ($p<0.01$). However, the reaction time task and visual detection task eccentricity results should be regarded with caution as there were a high number of variables in the analyses reducing the statistical power of this result. All results can be seen in Appendix C. There was no effect of years of experience found for the remaining tests.

5 Discussion

5.1 Introduction

This chapter seeks to expand and explain on the findings of the results section (4). The primary objective of this chapter is to establish a relationship between the initial assumptions made in the hypotheses and the outcomes of the procedures of the study.

The analyses conducted were a repeated measures analysis of variance (ANOVA) with a Tukey post hoc test on any significances found. The analyses focused on the effects of condition, difficulty and repetition with the main focus put on any condition effects found. Effects of difficulty were expected as increasing the difficulty of a task is likely to cause a reduction in task performance with the task becoming more difficult to complete correctly. As a result the focus of the discussion will be on the condition effects found.

5.2 Response to the hypothesis

The statistical analyses lead to the following responses to the hypotheses:

1) The performance in the visual detection task was expected to be different between the three conditions. A significant difference was found for each condition in all aspects of the visual detection task. The difference was found to be between the land condition and both underwater conditions.

2) The performance in the reaction time task was presumed to be different between the three conditions. There was no significant difference found between the conditions.

3) The performance in the memory recall task was expected to be different between the conditions. The effect of condition was found for the response times in the memory recall task but no significant difference was found for the percentage correct responses. The significant difference found for response time was found to be between the land and apnea conditions.

4) The performance in the recognition task was presumed to be different between the conditions. A significant difference was found for all aspects (errors detected, words read and reading speed) of the recognition task. This difference was found to be between the land and assisted breathing conditions only.

5) The performance in the tracking task was expected to be different between the three conditions. There was no significant difference found between the three conditions for the tracking task.

5.3 Condition effects

Condition effects were found in all aspects of two tasks in the study, the visual detection and recognition tasks, and in the response time aspect of the memory recall task. The percentage correct responses aspect of the memory recall task and the two remaining tasks, the reaction time and tracking tasks, showed no significant differences due to condition.

The condition effects that were found to be between the land condition and both underwater conditions are likely to be caused by the submersion in water, if there was no difference found between the two underwater conditions. Effects found between the land condition and one of the underwater conditions are thought to be a result of an aspect specific to that underwater condition, breathing type or possible distractions. The effects found between the two underwater conditions are thought to be due to an aspect of one of the conditions other than submersion in water, as this would be expected to show in both underwater conditions. These effects and possible causes will be elaborated on in the following sections in relation to the different tasks performed during the testing for the study.

5.3.1 Visual detection task

Condition effects were found for all aspect of the visual detection task (4.7). The effects found and the different aspects of the task where the effects were found will be elaborated on below.

The four aspects of the visual detection task were: response time (4.7.1), percent overlooked stimuli (Appendix B1), number of stimuli detected (Appendix B1) and the eccentricity response time (4.7.2). The condition effects found in the first three aspects of the task were all between the land and both underwater conditions. The condition effect in the eccentricity response time was between the two underwater conditions. However the focus of the analysis on the eccentricity response time was to determine if there was difference in the mean response times at the two different eccentricities (0-3.93º and 3.93-7.87º).

The difference in the responses between the land condition and both underwater conditions is most likely a result of a common aspect within both conditions. As there was no significant difference between the two underwater conditions, it indicates that the submersion in water appears to be the common factor that differentiates both underwater conditions from the land condition. Submersion in water has an impact on visual functioning as vision is altered underwater with the transition of light changing and the distorting of the image on the retina (Kinney et al., 1968; Kinney, McKay, et al., 1970; Luria & Kinney, 1970). This changed visual functioning would result in a reduced capacity to identify objects and as a result reduce ones' ability to respond correctly or timeously to the stimuli. Along with visual changes there are multiple physiological effects on the human body with regards to sympathetic and parasympathetic nervous system activations (Heusser et al., 2009; Schipke & Pelzer, 2001). These changes in activation, either up or down regulation, may impact on a person's cognitive performance as there would be changes in physiological responses in the body, such as heart rate or blood pressure. Changes in heart rate may also have an impact on HRV, which is also affected by cognitive effort. The combination of physiological responses to the environment and to the cognitive effort of the task may impact overall functioning in the task. The visual detection task being a search and target acquisition task would have required focused attention (Wickens, 1984). This attention would require attentional resources that would also be used or misused by distractive elements of the underwater conditions. In the apnea condition, the distraction of not breathing or needing to breathe would be present as well as the physical pressure of being underwater and the weightlessness of the limbs while being held down by the weight belt. In the assisted breathing condition there are the same distractions caused by being underwater, as well as the noise and bubbles from the scuba diving regulator coupled with the sensation of breathing underwater and breathing compressed air. All of these factors may have played a role in the reduced performance across all of the aspects of the task. However, it is likely that a combination of these factors is the cause of to reduced performance for both underwater conditions.

5.3.2 Memory recall task

The memory recall task had a condition effect for speed but not for accuracy (4.6). There was also a condition effect found for the response time but there was no effect found of percent correct responses. The effect found for response time will be elaborated on in this section.

The condition effect was found between the land and apnea conditions. The two aspects that differ the apnea condition from the land condition are the submersion in water and breath hold. Both aspects cause changes in sympathetic and parasympathetic nervous system responses (Heusser et al., 2009; Schipke & Pelzer, 2001). These changes in activation in the physiological responses within the body, caused by noticeable stressors around the person, would in turn have an impact on attentional resources and their allocation through the mechanisms of arousal and distraction. However, no significant difference between the assisted breathing condition and either of the other conditions, indicates that the difference between the apnea and land condition responses can be attributed to the apnea aspect of the apnea condition. Breath hold as a stressor increases as time progresses, as the need to breathe would become more apparent. This stress, highlighting the persons need to breathe, may detract resources from the task as there would be focus placed on the time remaining and when the next breath would be possible (Wickens, 1984). Any stress felt during a task may become a negative aspect of the memory, which in turn may hamper recall as there is a tendency to focus on the negative aspects of a memory during recall (Talarico et al., 2009). This focusing on the negative aspect of the memory would result in a longer time to recall and a slower response time, as was seen in the apnea condition.

A difference due to the submersion in water would have manifested itself in both the apnea and assisted breathing conditions. As there was no effect found for the assisted breathing condition with regards to either speed or accuracy the submersion in water is not likely to be the cause of the reduced response time in the task. Apnea has multiple effects on responses within the body which may in turn have an impact of memory recall performance. The actual act of apnea, not breathing, may have resulted in reduced performance toward the end of the breath hold phase, and as a result the participants may have experienced an elevated level of stress, and some may have become more panicked due to this experience. It should be noted that the sensation of running out of air is actually driven by the need to exhale the build up of carbon dioxide accumulating in the body. This stress or panicked feeling may have slowed the participants' recall, seen in Figure 13, as the distraction by or focusing on the stress may have hindered their ability to recall quickly (Talarico et al., 2009). This however only applies to those who's confident breath hold times that were not much longer than thirty seconds compared with participants whose repeated breath hold fitness was more developed. Experience in water may have somewhat negated the stress effects, however, this would also only apply to participants who's years of experience were apnea specific.

5.3.3 Reaction time

No condition effect was evident in the reaction time task (4.4), although an effect for difficulty and repetition was found (Appendix B2).

The lack of a condition effect in this task indicates that the processing of the task was not impacted by the breathing modality or submersion in water. Figure 11 shows that there are differences in the participants' mean reaction times across the three conditions, indicating that simple reaction time and choice reaction time, with two stimuli, are impacted by either submersion or breathing modality. However, the differences between the conditions are not significant. This finding indicates that aspects of either underwater conditions, such as submersion and breathing modality, which have impacted on cognitive function in other tasks in this study have had less impact of the speed processing of basic responses to simple stimuli. This could be a result of the simplicity of the task and indicate that more varied or complex processing is impacted by the conditions but basic or simpler processing remains largely unaffected.

5.3.4 Recognition

Condition and difficulty effects for percent errors detected, number of words read and reading speed were found in the recognition task (4.5). The condition effect was found to be between the land and assisted breathing conditions. The effects found will be elaborated on in this section.

The number of errors detected was significantly lower in the assisted breathing condition compared to the land condition. The number of errors detected was also lower in the assisted breathing condition than the apnea condition but this difference was not significant. The reverse was found for the words read and reading speed results in the assisted breathing condition. More words were read and a higher reading speed than both other conditions was evident, with the difference compared to the land condition being significant. Although performance was poorer in the apnea condition in comparison to the land condition in all three aspects, the differences between the two were not significant. The condition effect being limited to being between the assisted breathing and land conditions indicates that there are one or more aspects of the assisted breathing condition that hinder participant's the performance in the task. The reduced performance is not likely to have come purely from the submersion in water, as that should have resulted in there being a significant difference between the land and both underwater conditions. Therefore the difference can most likely be attributed to the use of the scuba apparatus. The performance in the recognition task may have been hampered by the noise and bubbles caused by the use of the scuba apparatus. The noise or feedback from the regulator results in a parasympathetic nervous system activation (Schipke & Pelzer, 2001) and may have been unfamiliar for participants whose experience underwater was not with scuba diving. Noise as a distractor is one that cannot be blocked out and as such the constant noise throughout the task may have drawn attentional resources away from the task due to the distraction (Wickens, 1984). The bubbles generated by the scuba apparatus during breathing would float up past the persons face and this too may have caused some distraction as well as possibly hampered their vision if the bubbles were in front of the persons face. However, the regulator used was designed to split the stream of bubbles around the persons face to avoid interfering with the person's vision, but it may not have completely prevented it.

5.3.5 Tracking Task

No statistical significances for condition or repetition were found for the tracking task (4.8). The tracking task using the low fidelity driving simulator, only had one level of difficulty. The tracking task being relatively simple may not have been sufficiently taxing enough, cognitively, to elicit an effect in any of the conditions as it appears that simple processing is not affected by submersion or breathing modality.

5.4 Implications

The findings of this study have relevance to underwater work and underwater workplaces outside of the research field. Divers and diving inspectors are required to be aware of their surroundings, knowing what is happening around them with particular regard to both the task at hand and their safety. The findings of this study show different cognitive tasks, that require different processes, are affected differently by the different conditions.

Diving inspectors are required to observe and make reports and decision regarding the structure that is being inspected (Kelly, 1999). This requires the inspectors to be able to identify the issue accurately and remember or relay that information to the surface. Being underwater with assisted breathing has been shown to negatively impact on the detection of errors in the recognition task which suggests that there is a possible impact of the use of assisted breathing when identifying something small that is out of place or incorrectly placed. However, the recognition task dealt specifically with text recognition which may vary from identifying faults in an underwater structure. When inspecting structures there are specific things that are looked for depending on the material the structure is made of (Kelly, 1999). Identifying a specific item and/or symbol in this case a star shaped stimuli, which was affected by both underwater conditions. If the material being inspected required the identification of small faults within a larger surface from which a fault may not differ significantly, the submersion in water, regardless of breathing modality, may result in impaired performance and a reduced detection rate of faults. This issue is somewhat combatted during diving inspections by the presence of a second diving inspector looking at the same area of the structure (Kelly, 1999), however, if one diving inspector could miss a fault it is likely both could.

Decision making, in the form of choice reaction time, was not impacted on by the underwater conditions which implies divers' abilities to react appropriately to an event or something in their vicinity is not impaired. However, reaction time did increase over time, showing that reactions slowed the longer the participant was performing the task. Task monotony and fatigue may impact on performance and reduce reaction times (Wickens, 1984). This in turn could endanger the diver as slowed reaction times may not allow them to respond timeously to a situation that is potentially threatening.

Breath hold divers are exposed to many of the same risks as other divers but are in the underwater environment without an air supply. The results of this study showed that in apnea response times for recall were slowed, indicating that while underwater and in apnea a diver's ability to recall a memory takes longer. Their accuracy is unchanged, but the time, between when the recall is needed and when it is given, is increased. As a result the divers' response to situations that require more than a kneejerk reaction is slowed or reduced. In a dangerous situation this lag time in recall may have serious implications for the diver as the ability to remember the appropriate response is key in executing the response (Wickens, 1984).

Overall the impacts on cognitive functioning found in this study may have a wide array of implications on performance in real world settings. The effect of condition on work performance should not be ignored as there are both practical and safety implications for reduced performance in underwater workplaces, for both the diver in the water and the task as a whole. Research into task and job specific impacts of condition is required. However, laboratory based research does provide an insight into the broader picture concerning the effects of submersion in water, along with breathing modality, and demonstrates how these impact on a diver's ability to perform their job or task timeously, effectively, and safely..

6 Conclusion

6.1 Study outcomes

The current study focused on the effect of submersion and breathing modality on different stages of the information processing chain, where specific cognitive tasks were compared across three conditions; land, underwater with assisted breathing and underwater in apnea. The conditions were chosen as assisted breathing and apnea are two popular forms of diving and are often used both recreationally and professionally. How task performance was affected in the three conditions was tested by using a cognitive test battery.

The findings in the study show that performance in different cognitive tasks were affected by different conditions while performance in other tasks was not influenced. When all the data was analysed it showed that there was no significant impact of condition on simpler tasks (reaction time and tracking). However, there were condition effects found for the recognition, memory and visual detection tasks. Submersion in water affected speed and accuracy in the visual detection task, assisted breathing caused an increase in speed and a decrease in accuracy in the recognition task, and apnea caused a decline in recall speed in the memory task.

6.2 Limitations

There were a number of factors in the study design that may have impacted on the results obtained. These include the nature of the cognitive tasks as they test the different stages of the information processing chain but do not represent a real world example of the use of the cognitive skills being tested. However, these tasks were used as they were representative of standardised ergonomics evaluations and were known to test specific aspects of the information processing chain, which was the main focus of this study. Linked to the nature of the tasks used, the test battery length may have impacted on the findings due to the limited exposure time it gave to each of the conditions. The shorter task lengths were chosen to maximise the number of participants that could be included in the study but did not result in all the participants, particularly in the apnea condition, being pushed to a limit that may have shown the impact of extended exposure to the condition.

The number of participants included in the study (n=18) could have been higher to give a greater statistical power to the findings in the study. However, given the time frame in which data collection was conducted and the population the participants were drawn from the smaller sample size was required. The varied nature of the participants' underwater experience may have added variability to the study's data as comfort or confidence in one type of underwater activity may not carry to other types. For example a participant who was a confident and competent scuba diver may not have found themselves comfortable or confident in the apnea condition of the study and vice versa, and this may have had a confounding impact on the results. This issue, as with the participant numbers, was unavoidable as there was a limited population available to the researcher from which to get participants.

The environmental conditions surrounding the testing; water temperature, water clarity and light conditions were all optimised for the data collection. This was done to ensure the participants were able to conduct and complete the tasks as accurately possible. This does not represent the environment in which participants would normally be finding themselves in real world scenarios but is a result of laboratory based testing. Without controlling these factors the data collection would not have been as effective. Even though not representative of real world scenarios, it allowed for a consistent environment and kept the focus of the data on the testing conditions and no other stressors. A factor that may have been possible to include was the danger aspect of underwater work in the forms of; currents, obstacles or predators in the water that may pose a threat, this would simulate a more realistic real world scenario in a laboratory setting.

The study design was unbalanced, having two underwater conditions and only one land based condition which may have resulted in some ambiguity in the results found. Having a balanced study design may have resulted in fewer ambiguous results and may have shed light on possible mechanisms underpinning the effects found in the study.

The current study utilise the Wickens (1984) model as a basis of cognitive functioning and it must be noted that Wickens (1984) is not the only available model of cognitive processing and other models may place emphasis on different aspects of cognitive functioning or may approach cognitive functioning from another perspective.

The final limitation is that no measures of cognitive effort (Heart Rate Variability) or physiological measures, for example heart rate were taken during the testing. Having this information may have added another insight into the various impacts on performance observed in the difference conditions. The physiological effects of both submersion and breathing modality are known but measuring those variables with the combination of submersion in water and breathing modality may, when combined with cognitive tests provide new insights into the field of cognitive function and underwater work. This was not done as waterproof equipment required to measure these variables continuously while underwater was not available to the researcher and as a result could not be measured.

6.3 Recommendations

The following recommendations are made for the consideration of future research into the effect of submersion and breathing modality on cognitive performance:

1. A longer testing protocol to allow for testing of cognitive performance in the different conditions over time and the length of use impact of the breathing modalities.
2. Test the apnea condition to voluntary termination; in which the participants would perform the different tasks until they opted to stop. This would allow for the analysis of the impact of running out of air on decision making and would hold real world applications, allowing for insight into decision making of breath hold divers towards the end of their breath hold capability.
3. Modify the tasks used to be more real world specific. The nature of the task can remain the same but the content in the task should be adapted to resemble real world scenarios or items that divers would come across when in open water.
4. Use real world conditions for data collection with regards to temperature and turbidity. The two may be tested in isolation and a determination may be made as to which impacts work performance more in the field.

5. Measure a variable of cognitive effort through the test battery, such as heart rate variability (equipment permitting). This would allow for a deeper understanding of how much more, or less, cognitive effort is required to conduct work in an underwater setting.
6. Record self-report measures of exertion throughout the testing process.
7. Lastly, measure physiological responses to the different conditions and tasks in the test battery (e.g. Heart Rate). This would allow for the measurement of these variables while completing cognitive tasks and would possibly provide evidence regarding the impact of the nature of the work coupled with the environment as opposed to either aspect on its own.

6.4 Future directions

Given the scope of the current study, the results provide insight into the effects of submersion in water and breathing modality on cognitive functioning. The results highlight that the speed and accuracy components of different tasks were affected differently. There was a significant improvement in speed, and a significant decrease in accuracy for the recognition task in the assisted breathing condition. However, there was a negative impact due to submersion in water for both speed and accuracy in the visual detection task. Speed in the memory task was negatively affected by the apnea condition but accuracy remained unaffected in all conditions. These findings have scope for both real world and research applications. The current study provides a suitable platform from which further research into more real world and job specific areas can be done. Applying the findings of this study to active underwater workplaces may reduce or explain incidents related to missed information in all job types. The application of the knowledge gained in this research may provide increased understanding into human functioning underwater and its relationship to cognitive performance. This would lead to improved efficiency and safety in underwater workplaces.

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Appendices

Appendix A – General information

1. Letter of information to participants
2. Participant consent form
3. Parent/guardian consent form – for 18 year old participants still at school
4. Participant details form
5. Permutation tables
6. Ethical approval

Appendix A1

Letter of information to participants

RHODES UNIVERSITY

Grahamstown • 6140 • South Africa

HUMAN KINETICS & ERGONOMICS

Tel: (046) 603 8471 • Fax: (046) 603 8934 • e-mail:

c.christie@ru.ac.za/j.mcdougall@ru.ac.za

Date: __/__/__

Dear Participant,

Thank you for volunteering to participate in this Masters research project. Your help and participation is greatly appreciated. This letter aims to inform you of the nature and proceedings of the Master's research project titled:

THE EFFECTS OF SUBMERSION IN WATER AND BREATHING MODALITY (ASSISTED BREATHING AND APNEA) ON DIFFERENT STAGES OF THE INFORMATION PROCESSING CHAIN.

It is advised that you read through this document carefully and thoroughly before signing the informed consent. If there are any questions about the study please contact me (contact information at the end of the document).

AIMS OF THE STUDY

This study aims to quantify the effects of submersion underwater and breathing modality, assisted breathing and apnea (breath hold), on information processing. Research has shown that there is a reduction in the information processing performance of divers when underwater. However it is not known which aspects of the information processing chain are affected by submersion in water and the breathing modality in use, either assisted breathing (using scuba gear) or apnea (breath hold). The ability to quantify which aspects of the information processing chain are effected by submersion and/or breathing modality can help to inform training and assessment for underwater occupations, such as inspection diving. If the training for occupational divers can be more informed and specific it will support both the industry and the divers.

As a result, this study will be conducted underwater, and on land. During the conditions you will be required to complete five different information processing tasks. Your participation will require you to come into the Human Kinetics and Ergonomics Department (HKE), Rhodes University for four separate sessions.

TESTING SESSIONS

SESSION 1:

The first session will be an information and habituation session in which you will be given all the information pertaining to this research project and will be given an informed consent form to read through. The researcher will then answer any questions you have, once all your questions are answered to your satisfaction you will sign the informed consent form. After all the information has been given to you, all your questions have been answered and you have signed the informed consent the researcher will record your weight, indicated on a scale. Once you have been weighed you will have the opportunity to be seated in the control and test condition setups.

SESSION 2, 3 & 4:

The second, third and fourth sessions will consist of the two underwater conditions and on land condition. The order in which you will do these conditions will be permutated. It is in these three sessions that you will complete the test battery. The duration of the test battery is approximately 15 minutes, taking into account the change over time between each test. Please remember to bring a comfortable swimming costume, towel and water bottle with you to all the testing sessions. Prior to all conditions please avoid any caffeinated and/or alcoholic drinks for 24 hours and do not smoke for 3 hours prior to the testing. Please avoid eating a heavy meal immediately prior to the testing.

TESTING CONDITIONS

LAND CONDITION

For the land condition you will be seated at a testing station that is identical to the underwater station but on land. At this station you will complete all of the information processing tasks while breathing normally.

ASSISTED BREATHING CONDITION

The assisted breathing condition is one of the underwater testing conditions. In this condition you will be seated at the bottom of the HKE hydrostatic weighing tank (2m depth). The hydrostatic weighing tank is a concrete above ground tank that is approximately 2 metres deep, 1 metre wide and 2 metres long with a glass window situated in one wall. When full the water level in the tank is approximately 1.8 metres deep, similar to that of a competitive swimming pool. You will be wearing a weight belt (4-6% of your body mass before submersion) to hold you into the seat, the buckle of the weight belt is designed for quick release and can be removed at any point if you wish to surface rapidly. There will be an air tank and a regulator in the tank that you will breathe with throughout the testing. You will perform all of the tests on a computer using a keyboard and a mouse while under the water. You will be asked to surface between tests.

APNEA CONDITION

The apnea condition will have the same setup as the assisted breathing condition, with you seated at the bottom of the hydrostatic weighing tank wearing a weight belt. You will complete the various tests on the computer using the same keyboard and mouse. When completing the tests in this condition you will do so in apnea (holding your breath). You will surface between each test.

RISKS

There are risks associated with this study but these risks are not higher than the risks you would take during your normal underwater activities. The risks you will be exposed during the assisted breathing condition are very low as you will have a steady air supply throughout the testing in the condition. The main risks of the study come from the apnea condition as you will be underwater holding your breath and wearing a weight belt. This risk is easily overcome as you will be able to kick yourself to the surface to the tank quite easily as the weight is only sufficient enough to hold you into the chair but not heavy enough to prevent you from surfacing. The weight belt is also easily removed should need to surface rapidly. During all testing conditions there will be a first aid kit and first aid qualified person present in the HKE department throughout the testing.

BENEFITS

There are benefits that you may gain from this study. You will gain an understanding into how your information processing is affected by your submersion in water and the breathing modality you use during your underwater activities. This information may explain experiences you have had or felt when operating underwater. There is also the possibility that there will be a training effect gained from repeated apneas resulting in slightly increased breath hold ability.

OTHER

Your participation in this research is completely voluntary and you are free to withdraw from the testing if you feel unable or unwilling to complete the testing. All information collected during this study will be kept confidential and codes will be used in lieu of any names. All photographs that are taken of you will be edited and all identifiable features will be blacked out. Also the findings of this research may be referenced in future studies for the purposes of thorough exploration of this area.

Thank you in advance for your interest in this research. I have provided my contact details below, should you have any questions please feel free to contact me.

Yours sincerely:

Luke Goodenough (Principal Researcher)

(M.Sc. Student – Human Kinetics and Ergonomics Department, Rhodes University)

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Supervisor:

Swantje Zschernack

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Appendix A2

Participant consent form

RHODES UNIVERSITY

Grahamstown • 6140 • South Africa

Human Kinetics and Ergonomics Department

INFORMED CONSENT AND INDEMNITY

For research involving human participants

I, ……………………………………………… have been fully informed of the research project entitled; **THE EFFECTS OF SUBMERSION IN WATER AND BREATHING MODALITY (ASSISTED BREATHING AND APNEA) ON DIFFERENT STAGES OF THE INFORMATION PROCESSING CHAIN.**

I have read the information sheet and understand the testing procedure that will take place. All testing procedures, associated risks and the benefits from partaking in this study have been verbally explained to me as well as in writing [*letter of information appended to this document*]. I have had ample opportunity to ask questions and to clarify any concerns or misunderstandings. I am satisfied that these have been answered satisfactorily. I understand that all data collected for publication purposes or re-use will be kept anonymous and all information gained in this regard will be treated confidentially. Furthermore,

- ☐ I consent to photographs, knowing that these will be altered to ensure my anonymity.

I understand that I am able to withdraw from the study at any point, irrespective of external influences placed on me by the researcher. In agreeing to participate in this research study I waive any legal recourse against the researchers from the Department of Human Kinetics and Ergonomics (HKE), Rhodes University, from claims resulting from personal injuries sustained whilst participating in the above mentioned research. I am aware and fully understand that the Department of Human Kinetics and ergonomics is not responsible for any injuries due to my personal negligence and non-compliance with instructions. This waiver shall be binding upon my heirs and personal representatives.

I have read and understood the above information, as well as the information provided in the letter accompanying this form. I therefore consent to voluntarily participate in this research project.

PARTICIPANT PROVIDING CONSENT:

(Print Name)	(Signed)	(Date)

WITNESS:

(Print Name)	(Signed)	(Date)

PRINCIPAL RESEARCHER:

(Print Name)	(Signed)	(Date)

Appendix A3

Parent/guardian consent form – for 18 year old participants still at school

RHODES UNIVERSITY

Grahamstown • 6140 • South Africa

Human Kinetics and Ergonomics Department

INFORMED CONSENT AND INDEMNITY

For research involving human participants

I, ………………………………………………… Parent/Guardian of ………………………………………………… have been fully informed of the research project entitled; **THE EFFECTS OF SUBMERSION IN WATER AND BREATHING MODALITY (ASSISTED BREATHING AND APNEA) ON DIFFERENT STAGES OF THE INFORMATION PROCESSING CHAIN.**

I have read the information sheet and understand the testing procedure that will take place. All testing procedures, associated risks and the benefits from partaking in this study have been verbally explained to me as well as in writing [*letter of information appended to this document*]. I have had ample opportunity to ask questions and to clarify any concerns or misunderstandings. I am satisfied that these have been answered satisfactorily. I understand that all data collected for publication purposes or re-use will be kept anonymous and all information gained in this regard will be treated confidentially.

I understand that the person under my guardianship is able to withdraw from the study at any point, irrespective of external influences placed on them by the researcher. In agreeing to the person under my guardianship participating in this research study I waive any legal recourse against the researchers from the Department of Human Kinetics and Ergonomics (HKE), Rhodes University, from claims resulting from personal injuries sustained whilst participating in the above mentioned research. I am aware and fully understand that the Department of Human Kinetics and ergonomics is not responsible for any injuries due to personal negligence and non-compliance with instructions. This waiver shall be binding upon my heirs and personal representatives.

I have read and understood the above information, as well as the information provided in the letter accompanying this form. I therefore consent to voluntarily participate in this research project.

PARENT/GUARDIAN PROVIDING CONSENT:

____________________	____________________	____________________
(Print Name)	(Signed)	(Date)

WITNESS:

____________________	____________________	____________________
(Print Name)	(Signed)	(Date)

PRINCIPAL RESEARCHER:

____________________	____________________	____________________
(Print Name)	(Signed)	(Date)

Appendix A4

Participant details form

PARTICIPANT DETAILS

Participant: ______________________ Code: p______

Age: _______ Gender: Male / Female

Years of underwater Experience: _________

Dry Body Mass: _______kg (_____kg belt)

Start Condition: ( ) Land / ( ) Apnea / ( ) Assisted

Start Task: ( ) Visual x2 / ( ) RT x1 / ( ) Memory x3 / ( ) Proof x3 / ( ) Driving x2

Start Difficulty: ( ) High / ( ) Low

Appendix A5

Permutation tables

Condition permutation

Table IX: Condition permutations for each participant.

Participant	Session		
	1	2	3
1	Land	Apnea	Assisted
2	Land	Assisted	Apnea
3	Apnea	Land	Assisted
4	Apnea	Assisted	Land
5	Assisted	Land	Apnea
6	Assisted	Apnea	Land
7	Land	Apnea	Assisted
8	Land	Assisted	Apnea
9	Apnea	Land	Assisted
10	Apnea	Assisted	Land
11	Assisted	Land	Apnea
12	Assisted	Apnea	Land
13	Land	Apnea	Assisted
14	Land	Assisted	Apnea
15	Apnea	Land	Assisted
16	Apnea	Assisted	Land
17	Assisted	Land	Apnea
18	Assisted	Apnea	Land
19	Land	Apnea	Assisted
20	Land	Assisted	Apnea

*The highlighted cells are the completed permutation that were not used for testing as the study design had 18 participants.

Task permutation

Table X: Task permutations for each participant.

Participant	difficulty Order	Permutation				
1	high/low	VDT	RT	Mem	Rec	Guide
2	low/high	VDT	RT	Guide	Rec	Mem
3	high/low	VDT	Rec	RT	Mem	Guide
4	high/low	VDT	Guide	Mem	Rec	RT
5	low/high	RT	VDT	Rec	Mem	Guide
6	low/high	RT	Mem	VDT	Guide	Rec
7	low/high	RT	Mem	Rec	Guide	VDT
8	low/high	RT	Rec	VDT	Mem	Guide
9	high/low	Mem	VDT	Guide	Rec	RT
10	high/low	Mem	Rec	Guide	RT	VDT
11	high/low	Mem	Guide	RT	VDT	Rec
12	high/low	Mem	Guide	Rec	VDT	RT
13	low/high	Rec	VDT	RT	Guide	Mem
14	low/high	Rec	VDT	Mem	Guide	RT
15	low/high	Rec	Mem	Guide	RT	VDT
16	high/low	Rec	Guide	Mem	RT	VDT
17	low/high	Guide	RT	Rec	VDT	Mem
18	high/low	Guide	RT	VDT	Mem	Rec
19	low/high	Guide	Mem	VDT	RT	Rec
20	high/low	Guide	Rec	RT	VDT	Mem

*The highlighted cells are the completed permutation that were not used for testing as the study design had 18 participants.

Appendix A6

Ethical Approval

Human Kinetics and Ergonomics
Ethics Committee Report

RHODES UNIVERSITY
Where leaders learn

Student Name: Luke Goodenough	
Project Title: The effect of submersion in water and breathing modality (assisted breathing and apnea) on different stages in the information processing chain	
Supervisor: Dr S Zschernack	**Type of Research**: MSc study
Application received: 01 Feb 2016	**Code:** 2016-02-01
Date received: 02-02-2016	**Date resubmitted:** 14-03-2016
Final Report compiled: 05 April 2016	

Dear Luke,

Your resubmission has been successful – the reviewers have approved your modifications. You may therefore continue with your experimental testing.

Please do however take note of the following comments made by reviewers during the resubmission review:

- I caution the candidate toward transparency, rather than defensiveness, on responses, and inclusions in the application. For instance, a particular area of concern is the fact that the tests have only ever been used "in house". This does not mean they cannot be used, but the candidate should simply mention this as a potential limitation to the validity/reliability of these tests.

Approved ✓	Approved, on condition that suggestions have been effected	Request for rework and resubmission	Rejected

On behalf of the HKE Ethics Committee I wish you all the best with your study.

Signed

MC Mattison
Chair: Human Kinetics and Ergonomics Ethics Committee

Confidential
HKE Ethical Committee Review Form

Appendix B – task performance ANOVAS

1. Visual detection task
2. Reaction time
3. Memory recall
4. Recognition
5. Tracking task

Appendix B1

Visual detection task

Table XI: Visual Detection Task, percent overlooked stimuli, ANOVA statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	773704.9	1	773704.9	1114.591	0.000000
Error	11800.7	17	694.2		
CONDITION	19792.7	2	9896.3	33.671	0.000000
Error	9993.0	34	293.9		
DIFFICULTY	276.8	1	276.8	3.732	0.070209
Error	1260.6	17	74.2		
REPETITION	3.8	1	3.8	0.075	0.786804
Error	858.7	17	50.5		
CONDITION*DIFFICULTY	57.1	2	28.6	0.318	0.729931
Error	3055.2	34	89.9		
CONDITION*REPETITION	3.0	2	1.5	0.016	0.984421
Error	3244.2	34	95.4		
DIFFICULTY*REPETITION	60.5	1	60.5	1.350	0.261354
Error	761.7	17	44.8		
CONDITION*DIFFICULTY*REPETITION	180.0	2	90.0	2.937	0.066615
Error	1042.0	34	30.6		

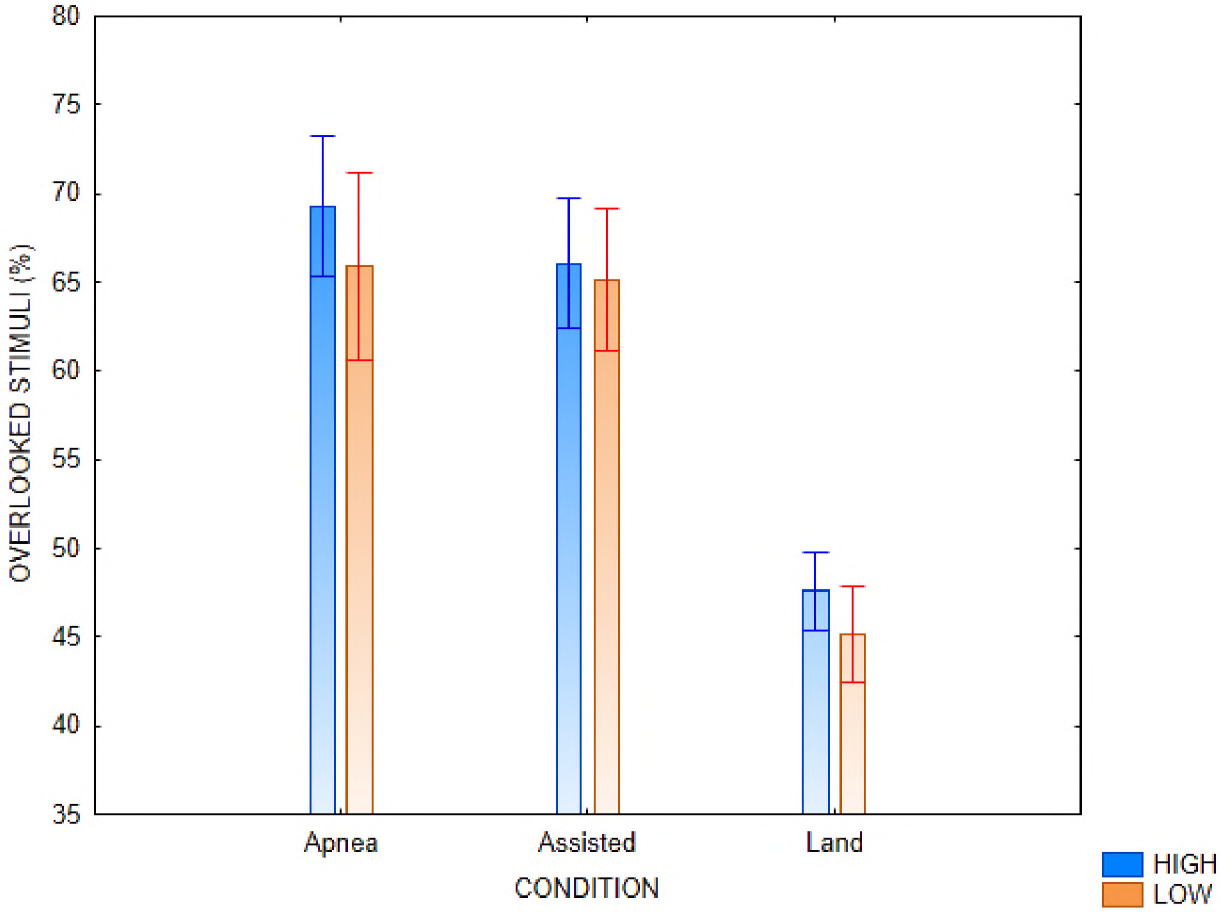

Figure 17: Visual detection task, percent of overlooked stimuli across the three conditions.

Table XII: Visual detection task, response time, ANOVA statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2.132828E+08	1	213282837	0.998961	0.331577
Error	3.629578E+09	17	213504617		
CONDITION	4.269881E+08	2	213494045	0.999949	0.378460
Error	7.259170E+09	34	213504996		
DIFFICULTY	2.362517E-02	1	0	4.933258	0.040218
Error	8.141229E-02	17	0		
REPETITION	2.135078E+08	1	213507808	1.000007	0.331331
Error	3.629609E+09	17	213506404		
CONDITION*DIFFICULTY	1.336744E-02	2	0	1.055718	0.359071
Error	2.152531E-01	34	0		
CONDITION*REPETITION	4.270162E+08	2	213508119	1.000011	0.378438
Error	7.259200E+09	34	213505871		
DIFFICULTY*REPETITION	1.758218E-04	1	0	0.036340	0.851073
Error	8.225033E-02	17	0		
CONDITION*DIFFICULTY*REPETITION	6.944749E-03	2	0	0.884020	0.422400
Error	1.335499E-01	34	0		

Table XIII: Visual detection task, eccentricity response time, ANOVA statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	98.28038	1	98.28038	1288.992	0.000000
Error	1.14369	15	0.07625		
CONDITION	0.22718	2	0.11359	4.668	0.017174
Error	0.72997	30	0.02433		
DIFFICULTY	0.02207	1	0.02207	1.687	0.213598
Error	0.19620	15	0.01308		
REPETITION	0.04131	1	0.04131	4.110	0.060790
Error	0.15079	15	0.01005		
ECCENTRICITY	0.00175	1	0.00175	0.247	0.626328
Error	0.10603	15	0.00707		
CONDITION*DIFFICULTY	0.92260	2	0.46130	21.377	0.000002
Error	0.64738	30	0.02158		
CONDITION*REPETITION	0.08601	2	0.04300	4.200	0.024651
Error	0.30717	30	0.01024		
DIFFICULTY*REPETITION	0.00240	1	0.00240	0.205	0.656885
Error	0.17490	15	0.01166		
CONDITION*ECCENTRICITY	0.01479	2	0.00740	1.046	0.363905
Error	0.21216	30	0.00707		
DIFFICULTY*ECCENTRICITY	0.00357	1	0.00357	0.351	0.562363
Error	0.15260	15	0.01017		
REPETITION*ECCENTRICITY	0.01232	1	0.01232	1.640	0.219752
Error	0.11267	15	0.00751		
CONDITION*DIFFICULTY*REPETITION	0.01103	2	0.00552	0.510	0.605651
Error	0.32455	30	0.01082		
CONDITION*DIFFICULTY*ECCENTRICITY	0.01039	2	0.00520	0.613	0.548153
Error	0.25412	30	0.00847		
CONDITION*REPETITION*ECCENTRICITY	0.00253	2	0.00126	0.110	0.896505
Error	0.34594	30	0.01153		
DIFFICULTY*REPETITION*ECCENTRICITY	0.01022	1	0.01022	1.876	0.190926
Error	0.08171	15	0.00545		
1*2*3*4	0.03370	2	0.01685	1.353	0.273897
Error	0.37370	30	0.01246		

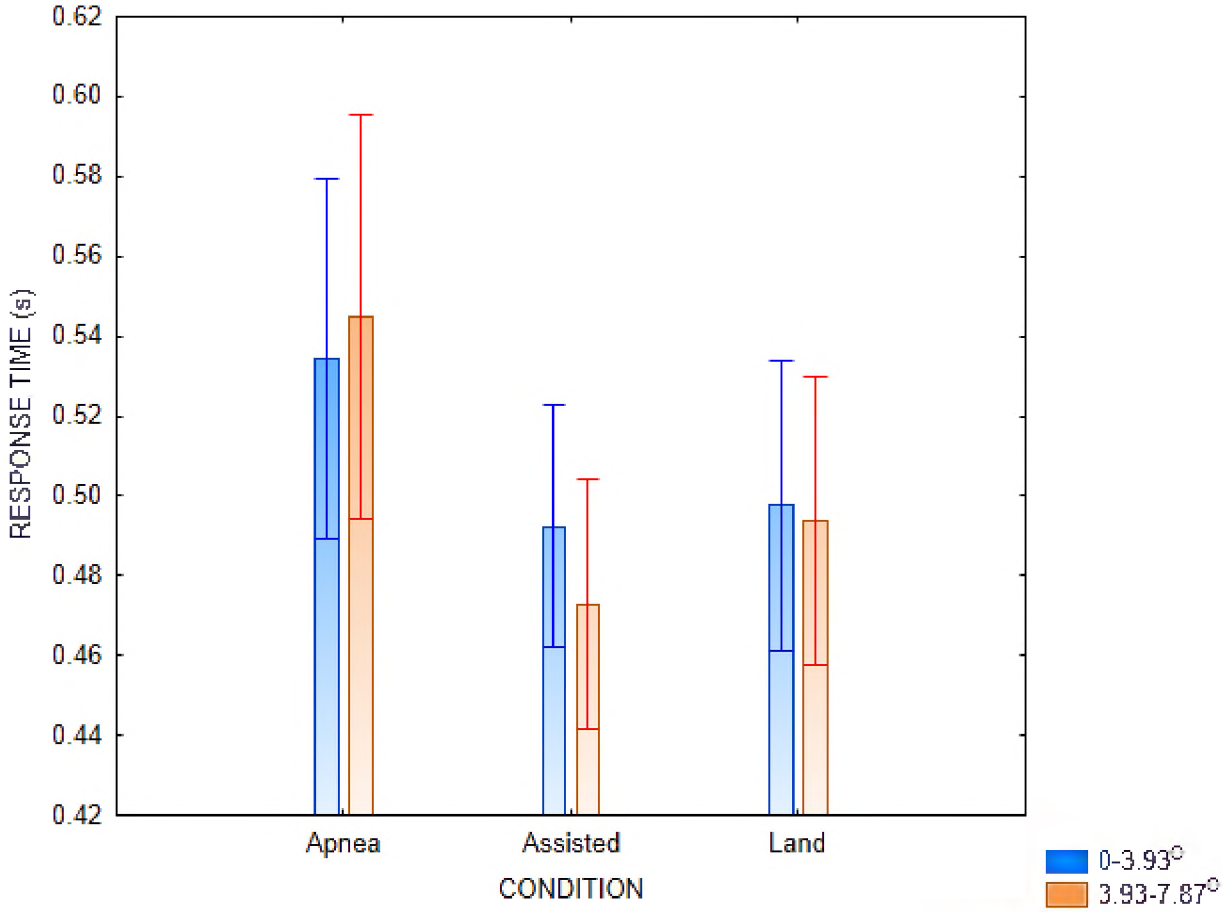

Figure 18: Visual detection task, response times at the two eccentricities of the task.

Table XIV: Visual detection task, number of stimuli detected, ANOVA statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	51553.56	1	51553.56	483.3529	0.000000
Error	1813.19	17	106.66		
CONDITION	3024.06	2	1512.03	38.0404	0.000000
Error	1351.44	34	39.75		
DIFFICULTY	31.89	1	31.89	4.6933	0.044781
Error	115.52	17	6.80		
REPETITION	2.04	1	2.04	0.6306	0.438087
Error	55.04	17	3.24		
CONDITION*DIFFICULTY	5.90	2	2.95	0.4179	0.661765
Error	239.94	34	7.06		
CONDITION*REPETITION	2.03	2	1.01	0.1722	0.842506
Error	200.14	34	5.89		
DIFFICULTY*REPETITION	2.45	1	2.45	0.5295	0.476734
Error	78.63	17	4.63		
CONDITION*DIFFICULTY*REPETITION	4.23	2	2.12	0.7577	0.476481
Error	94.94	34	2.79		

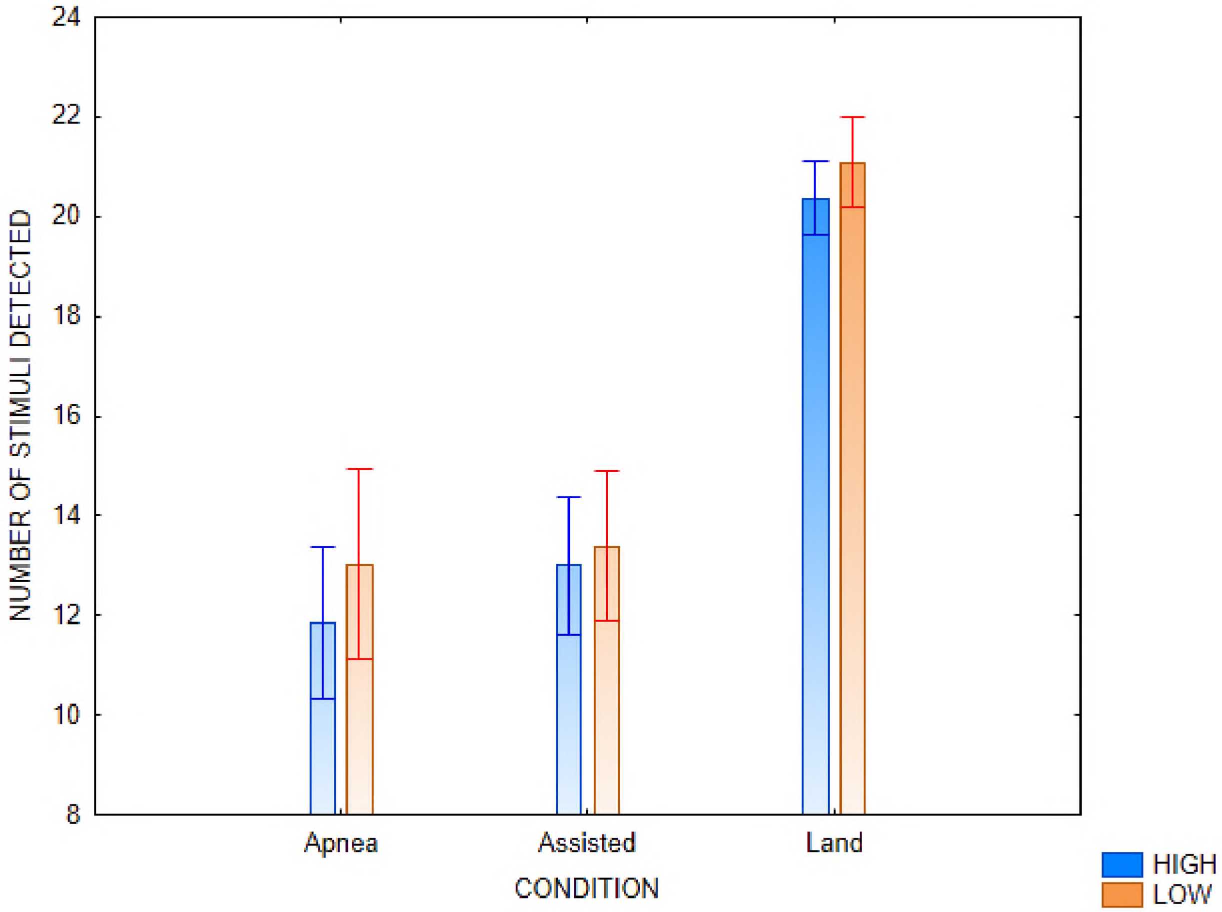

Figure 19: Visual detection task, number of stimuli detected across the three conditions.

Appendix B2

Reaction time task

Table XV: Reaction time task ANOVA statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	351.1469	1	351.1469	2945.551	0.000000
Error	2.0266	17	0.1192		
CONDITION	0.1367	2	0.0684	2.345	0.111200
Error	0.9912	34	0.0292		
DIFFICULTY	12.4219	1	12.4219	310.866	0.000000
Error	0.6793	17	0.0400		
REPETITION	0.4767	21	0.0227	2.339	0.000876
Error	3.4650	357	0.0097		
CONDITION*DIFFICULTY	0.0434	2	0.0217	0.857	0.433571
Error	0.8604	34	0.0253		
CONDITION*REPETITION	0.4517	42	0.0108	0.984	0.501373
Error	7.8013	714	0.0109		
DIFFICULTY*REPETITION	0.3386	21	0.0161	1.459	0.088526
Error	3.9446	357	0.0110		
CONDITION*DIFFICULTY*REPETITION	0.4595	42	0.0109	0.990	0.491778
Error	7.8934	714	0.0111		

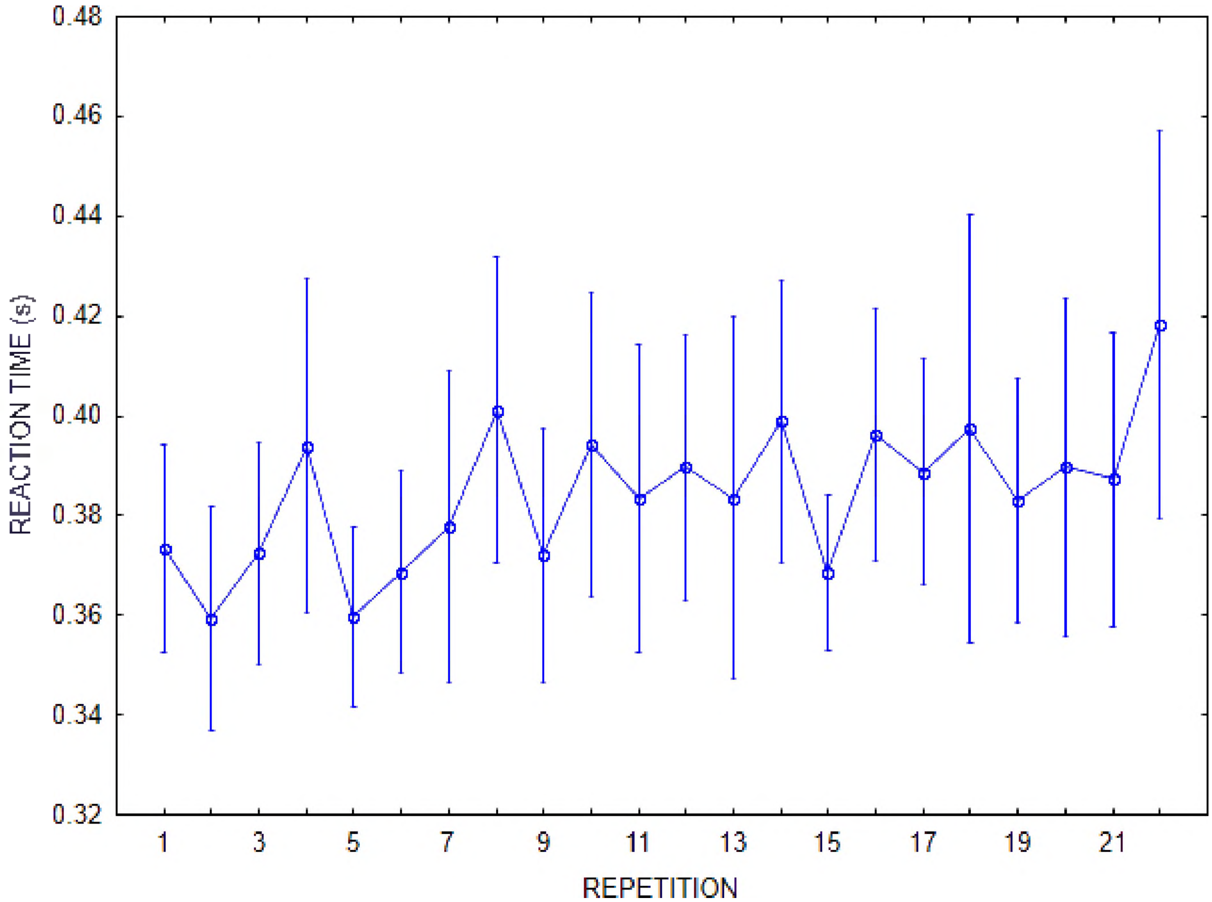

Figure 20: Reaction time task, reaction time over the repetitions.

Appendix B3

Memory recall task

Table XVI: Memory recall task, percentage correct responses, ANOVA statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	475565.8	1	475565.8	232.2864	0.000000
Error	34804.5	17	2047.3		
CONDITION	560.7	2	280.3	1.0198	0.371430
Error	9346.7	34	274.9		
DIFFICULTY	56337.4	1	56337.4	56.9718	0.000001
Error	16810.7	17	988.9		
CONDITION*DIFFICULTY	190.3	2	95.2	0.6137	0.547254
Error	5272.6	34	155.1		

Table XVII: Memory recall task, response time, ANOVA statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2.590918E+10	1	2.590918E+10	357.9662	0.000000
Error	1.230440E+09	17	7.237883E+07		
CONDITION	8.203953E+07	2	4.101976E+07	4.4617	0.019025
Error	3.125842E+08	34	9.193652E+06		
DIFFICULTY	1.478719E+09	1	1.478719E+09	66.4733	0.000000
Error	3.781701E+08	17	2.224530E+07		
REPETITION	6.683657E+07	5	1.336731E+07	2.6881	0.026418
Error	4.226787E+08	85	4.972690E+06		
CONDITION*DIFFICULTY	2.416895E+07	2	1.208447E+07	2.0941	0.138784
Error	1.962035E+08	34	5.770690E+06		
CONDITION*REPETITION	4.021264E+07	10	4.021264E+06	0.7105	0.713787
Error	9.621384E+08	170	5.659638E+06		
DIFFICULTY*REPETITION	9.120115E+07	5	1.824023E+07	3.7482	0.004087
Error	4.136402E+08	85	4.866355E+06		
CONDITION*DIFFICULTY*REPETITION	6.390019E+07	10	6.390019E+06	1.1963	0.296591
Error	9.080283E+08	170	5.341343E+06		

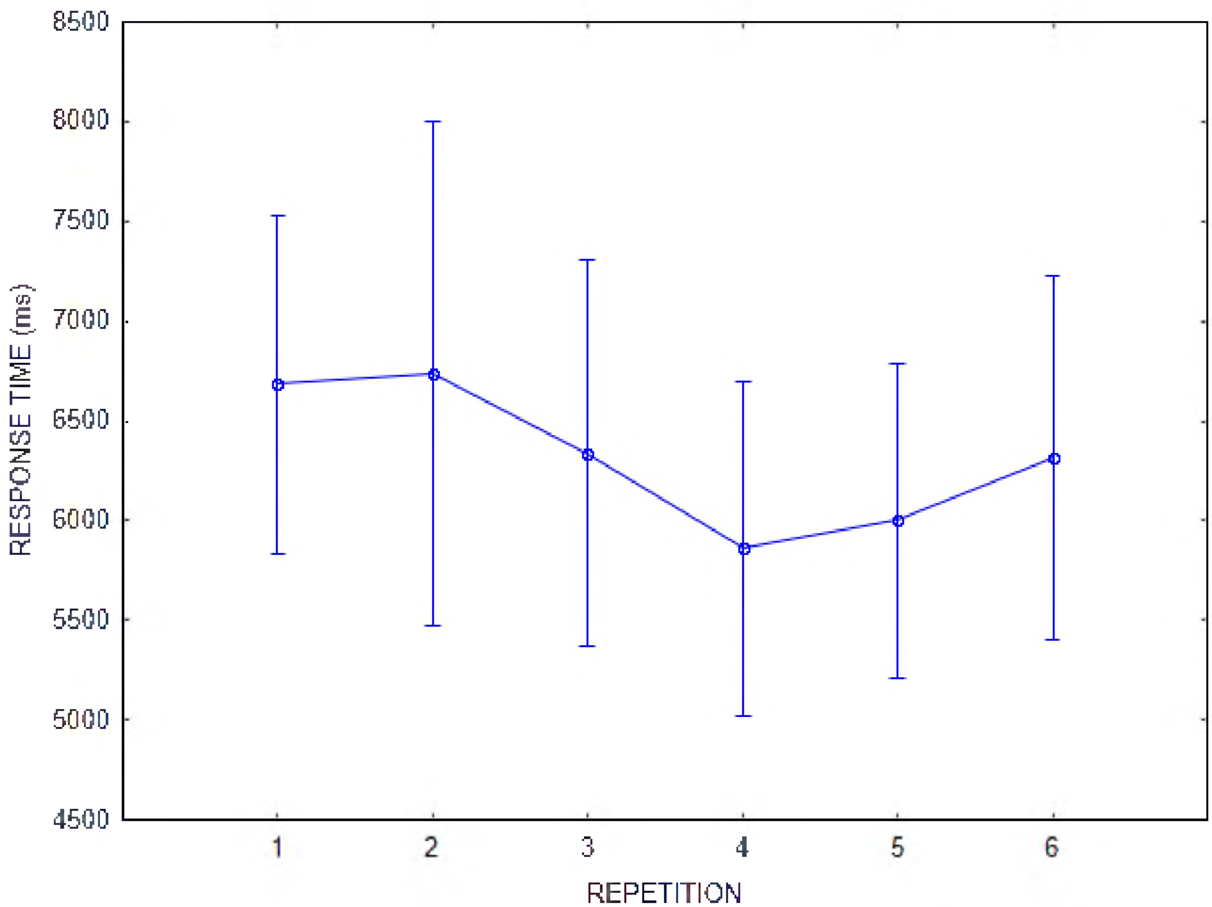

Figure 21: Memory recall task, response times over repetition.

Appendix B4

Recognition task (proof reading)

Table XVIII: Recognition task, percentage errors detected, ANOVA statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	66.22301	1	66.22301	1055.124	0.000000
Error	1.06698	17	0.06276		
CONDITION	0.25636	2	0.12818	5.114	0.011433
Error	0.85211	34	0.02506		
DIFFICULTY	0.23613	1	0.23613	12.931	0.002229
Error	0.31045	17	0.01826		
CONDITION*DIFFICULTY	0.00210	2	0.00105	0.090	0.914149
Error	0.39597	34	0.01165		

Table XIX: Recognition task, words read, ANOVA statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	10781288	1	10781288	305.4261	0.000000
Error	600086	17	35299		
CONDITION	27853	2	13926	3.4791	0.042202
Error	136096	34	4003		
DIFFICULTY	156180	1	156180	48.4435	0.000002
Error	54807	17	3224		
CONDITION*DIFFICULTY	5659	2	2829	1.8236	0.176891
Error	52753	34	1552		

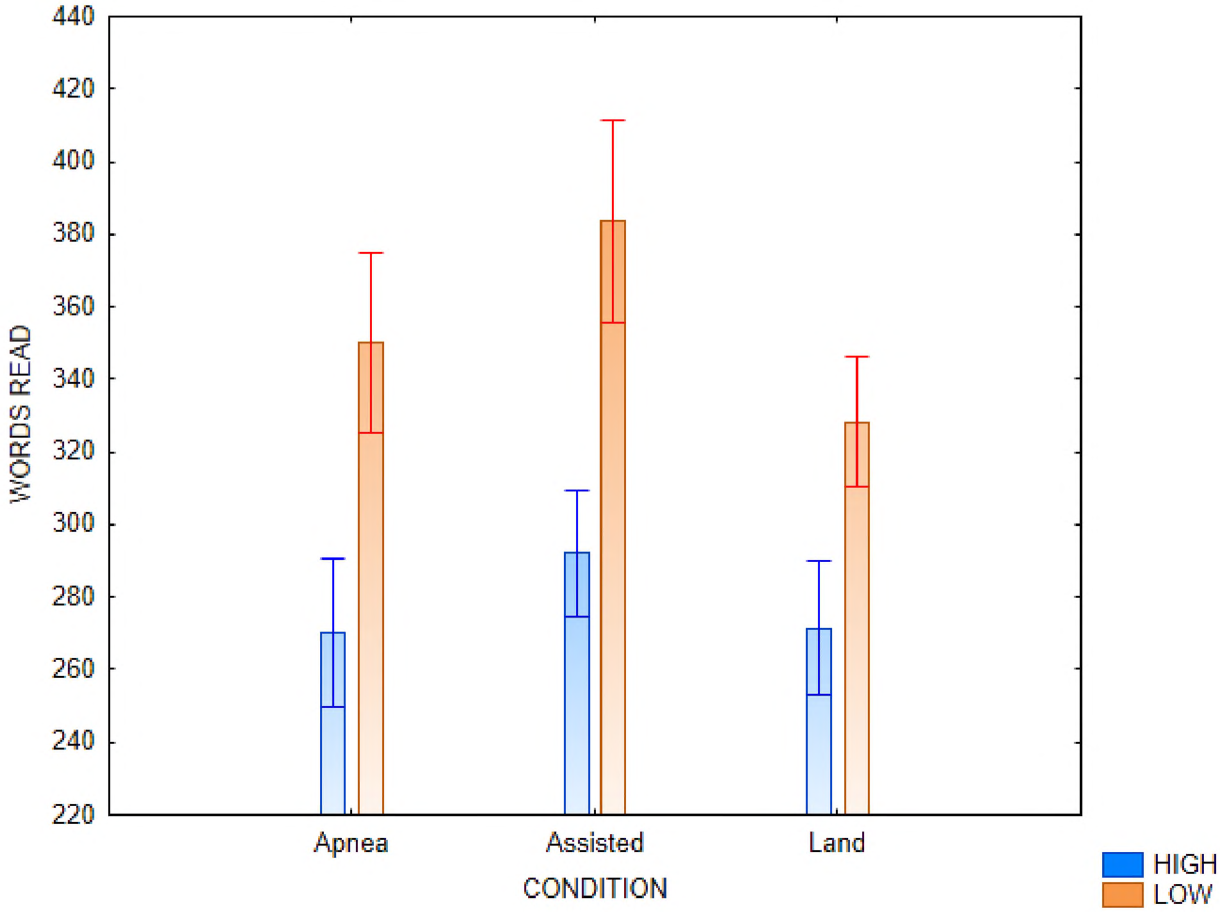

Figure 22: Recognition (proof reading) task, number of words read across the three conditions.

Table XX: Recognition task, reading speed, ANOVA statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	4791689	1	4791689	305.4247	0.000000
Error	266706	17	15689		
CONDITION	12380	2	6190	3.4795	0.042190
Error	60488	34	1779		
DIFFICULTY	69416	1	69416	48.4464	0.000002
Error	24358	17	1433		
CONDITION*DIFFICULTY	2515	2	1258	1.8237	0.176870
Error	23445	34	690		

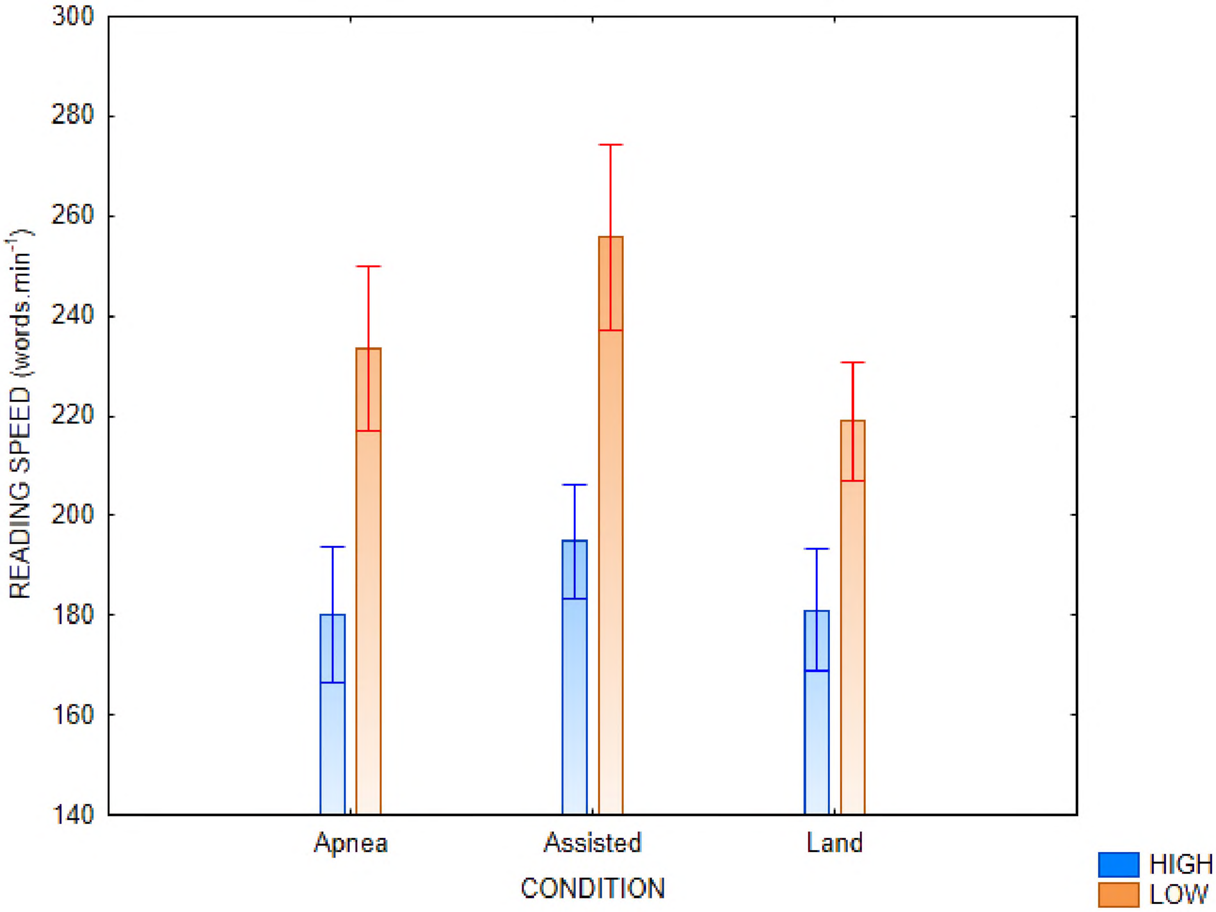

Figure 23: Recognition (proof reading) task, reading speed across the three conditions.

Appendix B5

Tracking task

Table XXI: Tracking task, mean deviation, ANOVA statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	0.048835	1	0.048835	44.09299	0.000004
Error	0.018828	17	0.001108		
CONDITION	0.000636	2	0.000318	2.15770	0.131158
Error	0.005008	34	0.000147		
REPETITION	0.000145	1	0.000145	3.00875	0.100909
Error	0.000818	17	0.000048		
CONDITION*REPETITION	0.000127	2	0.000064	0.48873	0.617646
Error	0.004429	34	0.000130		

Appendix C – years of experience

1. Visual detection task with years of experience as a continuous predictor
2. Reaction time with years of experience as a continuous predictor
3. Memory recall task with years of experience as a continuous predictor
4. Recognition (proof reading) task with years of experience as a continuous predictor
5. Tracking task with years of experience as a continuous predictor

Appendix C1

Visual detection task

Table XXII: Visual detection task, percent overlooked stimuli, ANOVA with years of experience as a continuous predictor statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	340995.3	1	340995.3	468.5160	0.000000
{1}Years of Experience	155.6	1	155.6	0.2138	0.650034
Error	11645.1	16	727.8		
{2}CONDITION	15045.6	2	7522.8	28.9519	0.000000
CONDITION*Years of Experience	1678.1	2	839.1	3.2292	0.052788
Error	8314.8	32	259.8		
{3}DIFFICULTY	119.2	1	119.2	1.5126	0.236521
DIFFICULTY*Years of Experience	0.0	1	0.0	0.0001	0.994056
Error	1260.6	16	78.8		
{4}REPETITION	30.0	1	30.0	0.5796	0.457539
REPETITION*Years of Experience	30.8	1	30.8	0.5948	0.451806
Error	827.9	16	51.7		
CONDITION*DIFFICULTY	333.4	2	166.7	1.9460	0.159375
CONDITION*DIFFICULTY*Years of Experience	314.0	2	157.0	1.8324	0.176421
Error	2741.3	32	85.7		
CONDITION*REPETITION	25.0	2	12.5	0.1257	0.882321
CONDITION*REPETITION*Years of Experience	64.2	2	32.1	0.3231	0.726202
Error	3179.9	32	99.4		
DIFFICULTY*REPETITION	1.0	1	1.0	0.0218	0.884468
DIFFICULTY*REPETITION*Years of Experience	29.0	1	29.0	0.6341	0.437519
Error	732.7	16	45.8		
CONDITION*DIFFICULTY*REPETITION	83.7	2	41.8	1.2857	0.290346
2*3*4*1	0.6	2	0.3	0.0088	0.991253
Error	1041.4	32	32.5		

Table XXIII: Visual detection task, response time, ANOVA with years of experience as a continuous predictor statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2.983652E+08	1	298365156	1.354187	0.261608
{1}Years of Experience	1.043328E+08	1	104332762	0.473534	0.501222
Error	3.525246E+09	16	220327858		
{2}CONDITION	5.970470E+08	2	298523487	1.354902	0.272374
CONDITION*Years of Experience	2.086580E+08	2	104329007	0.473516	0.627103
Error	7.050512E+09	32	220328495		
{3}DIFFICULTY	8.120287E-03	1	0	1.599503	0.224085
DIFFICULTY*Years of Experience	1.842920E-04	1	0	0.036301	0.851291
Error	8.122810E-02	16	0		
{4}REPETITION	2.985401E+08	1	298540114	1.354970	0.261476
REPETITION*Years of Experience	1.043337E+08	1	104333689	0.473534	0.501221
Error	3.525275E+09	16	220329699		
CONDITION*DIFFICULTY	3.211002E-03	2	0	0.252335	0.778516
CONDITION*DIFFICULTY*Years of Experience	1.165029E-02	2	0	0.915532	0.410534
Error	2.036024E-01	32	0		
CONDITION*REPETITION	5.970779E+08	2	298538926	1.354968	0.272357
CONDITION*REPETITION*Years of Experience	2.086652E+08	2	104332575	0.473530	0.627094
Error	7.050534E+09	32	220329202		
DIFFICULTY*REPETITION	1.591344E-04	1	0	0.030966	0.862523
DIFFICULTY*REPETITION*Years of Experience	2.723795E-05	1	0	0.005300	0.942865
Error	8.222303E-02	16	0		
CONDITION*DIFFICULTY*REPETITION	1.723065E-03	2	0	0.210642	0.811179
2*3*4*1	2.668683E-03	2	0	0.326242	0.724003
Error	1.308812E-01	32	0		

Table XXIV: Visual detection task, number of stimuli detected, ANOVA with years of experience as a continuous predictor statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	21377.13	1	21377.13	189.4311	0.000000
{1}Years of Experience	7.60	1	7.60	0.0674	0.798497
Error	1805.59	16	112.85		
{2}CONDITION	2230.66	2	1115.33	31.9134	0.000000
CONDITION*Years of Experience	233.08	2	116.54	3.3346	0.048368
Error	1118.36	32	34.95		
{3}DIFFICULTY	13.26	1	13.26	1.8371	0.194113
DIFFICULTY*Years of Experience	0.00	1	0.00	0.0005	0.982027
Error	115.52	16	7.22		
{4}REPETITION	8.00	1	8.00	2.6234	0.124836
REPETITION*Years of Experience	6.26	1	6.26	2.0538	0.171074
Error	48.78	16	3.05		
CONDITION*DIFFICULTY	23.46	2	11.73	1.6968	0.199345
CONDITION*DIFFICULTY*Years of Experience	18.70	2	9.35	1.3523	0.273017
Error	221.24	32	6.91		
CONDITION*REPETITION	0.65	2	0.32	0.0520	0.949416
CONDITION*REPETITION*Years of Experience	1.25	2	0.63	0.1006	0.904581
Error	198.89	32	6.22		
DIFFICULTY*REPETITION	0.01	1	0.01	0.0019	0.966086
DIFFICULTY*REPETITION*Years of Experience	2.17	1	2.17	0.4550	0.509623
Error	76.46	16	4.78		
CONDITION*DIFFICULTY*REPETITION	3.32	2	1.66	0.5903	0.560076
2*3*4*1	4.84	2	2.42	0.8602	0.432612
Error	90.09	32	2.82		

Table XXV: Visual detection task, eccentricity response times. ANOVA with years of experience as a continuous predictor statistica table 1.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	38.45833	1	38.45833	488.7013	0.000000
{1}Years of Experience	0.04196	1	0.04196	0.5332	0.477324
Error	1.10173	14	0.07869		
{2}CONDITION	0.16675	2	0.08337	3.3056	0.051427
CONDITION*Years of Experience	0.02375	2	0.01187	0.4707	0.629390
Error	0.70622	28	0.02522		
{3}DIFFICULTY	0.03074	1	0.03074	2.3224	0.149790
DIFFICULTY *Years of Experience	0.01089	1	0.01089	0.8226	0.379774
Error	0.18532	14	0.01324		
{4}REPETITION	0.00398	1	0.00398	0.3894	0.542637
REPETITION*Years of Experience	0.00769	1	0.00769	0.7525	0.400313
Error	0.14310	14	0.01022		
{5}ECCENTRICITY	0.02581	1	0.02581	4.7805	0.046261
ECCENTRICITY*Years of Experience	0.03044	1	0.03044	5.6372	0.032426
Error	0.07559	14	0.00540		
CONDITION* DIFFICULTY	0.45310	2	0.22655	9.9315	0.000550
CONDITION* DIFFICULTY *Years of Experience	0.00866	2	0.00433	0.1899	0.828082
Error	0.63871	28	0.02281		
CONDITION*REPETITION	0.03690	2	0.01845	1.7167	0.198026
CONDITION*REPETITION*Years of Experience	0.00621	2	0.00310	0.2889	0.751329
Error	0.30096	28	0.01075		
DIFFICULTY *REPETITION	0.02535	1	0.02535	2.4116	0.142745
DIFFICULTY *REPETITION*Years of Experience	0.02775	1	0.02775	2.6407	0.126451
Error	0.14715	14	0.01051		
CONDITION*ECCENTRICITY	0.00157	2	0.00078	0.1077	0.898304
CONDITION*ECCENTRICITY*Years of Experience	0.00814	2	0.00407	0.5582	0.578452
Error	0.20402	28	0.00729		
DIFFICULTY *ECCENTRICITY	0.00695	1	0.00695	0.6519	0.432935
DIFFICULTY *ECCENTRICITY*Years of Experience	0.00344	1	0.00344	0.3230	0.578812
Error	0.14915	14	0.01065		
REPETITION*ECCENTRICITY	0.00631	1	0.00631	0.7845	0.390732
REPETITION*ECCENTRICITY*Years of Experience	0.00012	1	0.00012	0.0143	0.906478
Error	0.11255	14	0.00804		
CONDITION* DIFFICULTY *REPETITION	0.04932	2	0.02466	2.8963	0.071895
2*3*4*1	0.08613	2	0.04306	5.0574	0.013332
Error	0.23842	28	0.00852		
CONDITION* DIFFICULTY *ECCENTRICITY	0.02235	2	0.01118	1.4108	0.260753
2*3*5*1	0.03230	2	0.01615	2.0383	0.149138
Error	0.22183	28	0.00792		
CONDITION*REPETITION*ECCENTRICITY	0.01268	2	0.00634	0.5308	0.593912
2*4*5*1	0.01165	2	0.00582	0.4877	0.619155
Error	0.33430	28	0.01194		
DIFFICULTY *REPETITION*ECCENTRICITY	0.01193	1	0.01193	2.1306	0.166458
3*4*5*1	0.00334	1	0.00334	0.5973	0.452480
Error	0.07836	14	0.00560		
2*3*4*5	0.00855	2	0.00428	0.3293	0.722167
2*3*4*5*1	0.01019	2	0.00509	0.3923	0.679137
Error	0.36351	28	0.01298		

Appendix C2

Reaction time

Table XXVI: Reaction time task ANOVA with years of experience as a continuous predictor statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	145.3840	1	145.3840	1181.300	0.000000
{1}Years of Experience	0.0575	1	0.0575	0.467	0.504141
Error	1.9691	16	0.1231		
{2}CONDITION	0.2019	2	0.1009	3.605	0.038728
CONDITION*Years of Experience	0.0951	2	0.0476	1.699	0.198991
Error	0.8960	32	0.0280		
{3}DIFFICULTY	4.7638	1	4.7638	116.463	0.000000
DIFFICULTY *Years of Experience	0.0248	1	0.0248	0.607	0.447139
Error	0.6545	16	0.0409		
{4}REPETITION	0.3149	21	0.0150	1.632	0.040500
REPETITION*Years of Experience	0.3776	21	0.0180	1.957	0.007752
Error	3.0873	336	0.0092		
CONDITION* DIFFICULTY	0.0188	2	0.0094	0.366	0.696307
CONDITION* DIFFICULTY *Years of Experience	0.0392	2	0.0196	0.764	0.474024
Error	0.8212	32	0.0257		
CONDITION*REPETITION	0.6630	42	0.0158	1.547	0.016454
CONDITION*REPETITION*Years of Experience	0.9443	42	0.0225	2.203	0.000030
Error	6.8570	672	0.0102		
DIFFICULTY *REPETITION	0.4767	21	0.0227	2.251	0.001511
DIFFICULTY *REPETITION*Years of Experience	0.5558	21	0.0265	2.624	0.000165
Error	3.3888	336	0.0101		
CONDITION* DIFFICULTY *REPETITION	0.3664	42	0.0087	0.840	0.755061
2*3*4*1	0.9100	42	0.0217	2.085	0.000104
Error	6.9834	672	0.0104		

Appendix C3

Memory recall task

Table XXVII: Memory recall task, percentage correct responses, ANOVA with years of experience as a continuous predictor statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	192250.8	1	192250.8	89.01630	0.000000
Years of Experience	248.9	1	248.9	0.11526	0.738652
Error	34555.6	16	2159.7		
CONDITION	216.7	2	108.3	0.37494	0.690312
CONDITION*Years of Experience	100.9	2	50.4	0.17460	0.840590
Error	9245.8	32	288.9		
DIFFICULTY	21954.8	1	21954.8	20.99839	0.000307
DIFFICULTY *Years of Experience	81.9	1	81.9	0.07835	0.783135
Error	16728.8	16	1045.5		
CONDITION* DIFFICULTY	73.9	2	36.9	0.22656	0.798538
CONDITION* DIFFICULTY *Years of Experience	53.9	2	27.0	0.16533	0.848337
Error	5218.7	32	163.1		

Table XXVIII: Memory recall task, response time, ANOVA with years of experience as a continuous predictor statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1.067625E+10	1	1.067625E+10	139.4725	0.000000
{1}Years of Experience	5.681994E+06	1	5.681994E+06	0.0742	0.788762
Error	1.224758E+09	16	7.654738E+07		
{2}CONDITION	8.151291E+07	2	4.075646E+07	4.4110	0.020328
CONDITION*Years of Experience	1.691388E+07	2	8.456941E+06	0.9153	0.410631
Error	2.956703E+08	32	9.239697E+06		
{3}DIFFICULTY	4.751928E+08	1	4.751928E+08	21.1795	0.000294
DIFFICULTY *Years of Experience	1.918624E+07	1	1.918624E+07	0.8551	0.368841
Error	3.589839E+08	16	2.243649E+07		
{4}REPETITION	5.431787E+07	5	1.086357E+07	2.2248	0.059747
REPETITION*Years of Experience	3.204073E+07	5	6.408147E+06	1.3123	0.267197
Error	3.906379E+08	80	4.882974E+06		
CONDITION* DIFFICULTY	9.521507E+06	2	4.760753E+06	0.9022	0.415746
CONDITION* DIFFICULTY *Years of Experience	2.734498E+07	2	1.367249E+07	2.5910	0.090586
Error	1.688585E+08	32	5.276827E+06		
CONDITION*REPETITION	4.738878E+07	10	4.738878E+06	0.8260	0.604105
CONDITION*REPETITION*Years of Experience	4.422161E+07	10	4.422161E+06	0.7708	0.656695
Error	9.179168E+08	160	5.736980E+06		
DIFFICULTY *REPETITION	4.604143E+07	5	9.208285E+06	1.9102	0.101760
DIFFICULTY *REPETITION*Years of Experience	2.799576E+07	5	5.599153E+06	1.1615	0.335445
Error	3.856444E+08	80	4.820555E+06		
CONDITION* DIFFICULTY *REPETITION	9.211207E+07	10	9.211207E+06	1.7893	0.066387
2*3*4*1	8.435630E+07	10	8.435630E+06	1.6386	0.100063
Error	8.236720E+08	160	5.147950E+06		

Appendix C4

Recognition (proof reading) task

Table XXIX: Recognition task, percentage errors detected, ANOVA with years of experience as a continuous predictor statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	28.52074	1	28.52074	428.1396	0.000000
Years of Experience	0.00113	1	0.00113	0.0169	0.898144
Error	1.06585	16	0.06662		
CONDITION	0.23043	2	0.11521	4.9035	0.013881
CONDITION*Years of Experience	0.10024	2	0.05012	2.1331	0.135014
Error	0.75187	32	0.02350		
DIFFICULTY	0.14165	1	0.14165	7.4461	0.014869
DIFFICULTY *Years of Experience	0.00607	1	0.00607	0.3190	0.580064
Error	0.30438	16	0.01902		
CONDITION* DIFFICULTY	0.05231	2	0.02616	2.7469	0.079261
CONDITION* DIFFICULTY *Years of Experience	0.09127	2	0.04563	4.7926	0.015114
Error	0.30470	32	0.00952		

Table XXX: Recognition task, words read, ANOVA with years of experience as a continuous predictor statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	4096041	1	4096041	114.0402	0.000000
Years of Experience	25406	1	25406	0.7073	0.412724
Error	574680	16	35918		
CONDITION	8266	2	4133	1.0005	0.378892
CONDITION*Years of Experience	3915	2	1957	0.4739	0.626889
Error	132182	32	4131		
DIFFICULTY	51888	1	51888	15.6045	0.001146
DIFFICULTY *Years of Experience	1604	1	1604	0.4824	0.497318
Error	53203	16	3325		
CONDITION* DIFFICULTY	77	2	38	0.0253	0.975067
CONDITION* DIFFICULTY *Years of Experience	4198	2	2099	1.3833	0.265335
Error	48555	32	1517		

Table XXXI: Recognition task, reading speed, ANOVA with years of experience as a continuous predictor statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1820462	1	1820462	114.0396	0.000000
Years of Experience	11292	1	11292	0.7073	0.412720
Error	255415	16	15963		
CONDITION	3674	2	1837	1.0007	0.378845
CONDITION*Years of Experience	1740	2	870	0.4740	0.626823
Error	58748	32	1836		
DIFFICULTY	23063	1	23063	15.6057	0.001146
DIFFICULTY *Years of Experience	713	1	713	0.4823	0.497334
Error	23646	16	1478		
CONDITION* DIFFICULTY	34	2	17	0.0253	0.975040
CONDITION* DIFFICULTY *Years of Experience	1866	2	933	1.3832	0.265363
Error	21580	32	674		

Appendix C5

Tracking task

Table XXXII: Tracking task, mean deviation, ANOVA with years of experience as a continuous predictor statistica table.

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	0.012681	1	0.012681	11.88423	0.003312
Years of Experience	0.001755	1	0.001755	1.64461	0.217963
Error	0.017073	16	0.001067		
CONDITION	0.001835	2	0.000917	8.50334	0.001092
CONDITION*Years of Experience	0.001556	2	0.000778	7.21287	0.002596
Error	0.003452	32	0.000108		
REPETITION	0.000190	1	0.000190	4.01929	0.062207
REPETITION*Years of Experience	0.000061	1	0.000061	1.29606	0.271693
Error	0.000756	16	0.000047		
CONDITION*REPETITION	0.000125	2	0.000062	0.45733	0.637047
CONDITION*REPETITION*Years of Experience	0.000073	2	0.000037	0.26904	0.765823
Error	0.004356	32	0.000136		

Appendix D – post hoc analyses

1. Visual detection task
2. Memory recall task
3. Recognition (proof reading) task

Appendix D1

Visual detection task post hoc

Table XXXIII: Visual detection task, number of stimuli detected, Tukey post hoc test.

Cell No.	CONDITION	{1} 12.431	{2} 13.194	{3} 20.722
1	1		0.749416	0.000125
2	2	0.749416		0.000125
3	3	0.000125	0.000125	

Table XXXIV: Visual detection task, percent overlooked stimuli, Tukey post hoc test.

Cell No.	CONDITION	{1} 67.592	{2} 65.596	{3} 46.361
1	1		0.766072	0.000125
2	2	0.766072		0.000125
3	3	0.000125	0.000125	

Table XXXV: Visual detection task, response time, Tukey post hoc test.

Cell No.	CONDITION	{1} .57650	{2} .54997	{3} .43381
1	1		0.559323	0.000131
2	2	0.559323		0.000303
3	3	0.000131	0.000303	

Table XXXVI: Visual detection task, eccentricity response time, Tukey post hoc test for condition.

Cell No.	CONDITION	{1} .53946	{2} .48258	{3} .49567
1	1		0.017771	0.079778
2	2	0.017771		0.781758
3	3	0.079778	0.781758	

Appendix D2

Memory recall task

Table XXXVII: Memory recall task, response time, Tukey post hoc test.

Cell No.	{1} 6766.9	{2} 6307.0	{3} 5895.8
1		0.269591	0.014162
2	0.269591		0.347561
3	0.014162	0.347561	

Appendix D3

Recognition (proof reading) task

Table XXXVIII: Recognition task, percentage errors detected, Tukey post hoc test.

Cell No.	{1} .79417	{2} .71861	{3} .83639
1		0.121698	0.501747
2	0.121698		0.009227
3	0.501747	0.009227	

Table XXXIX: Recognition task, words read, Tukey post hoc test.

Cell No.	{1} 310.08	{2} 337.89	{3} 299.89
1		0.164617	0.774652
2	0.164617		0.040219
3	0.774652	0.040219	

Table XL: Recognition task, reading speed, Tukey post hoc test.

Cell No.	{1} 206.72	{2} 225.26	{3} 199.93
1		0.164573	0.774681
2	0.164573		0.040210
3	0.774681	0.040210	