Original articles

Complex tactile performance in low visibility: the effect of nitrogen narcosis

Charles H van Wijk and Willem AJ Meintjes

Abstract

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Background: In a task-environment where visibility has deteriorated, individuals rely heavily on tactile performance (perception and manipulation) to complete complex tasks. When this happens under hyperbaric conditions, factors like nitrogen narcosis could influence a person's ability to successfully complete such tasks.

Objective: To examine the effect of nitrogen narcosis on a complex neuropsychological task measuring tactile performance at a pressure of 608 kPa (6 atm abs), in the absence of visual access to the task.

Methods: In a prospective cross-over study, 139 commercial divers were tested in a dry chamber at 101.3 kPa and 608 kPa. They completed the Tupperware Neuropsychological Task (TNT) of tactile performance without visual access to the task, and completed questionnaires to provide psychological and biographical data, which included trait anxiety and transient mood states, as well as formal qualifications and technical proficiency.

Results: A significant decrement (9.5%, $P < 0.001$) in performance on the TNT at depth was found, irrespective of the sequence of testing. Generally, neither the psychological nor biographical variables showed any significant effect on tactile performance. Tactile performance on the surface was a good indicator of performance at depth.

Conclusion: These findings have practical implications for professional diving where conditions of low visibility during deeper diving occur. Recommendations are made towards managing potential impairments in tactile performance, such as pre-dive practical learning ('rehearsal') as an aid to successful completion of tasks.

Key words

Nitrogen narcosis, deep diving, performance, psychology, diving research

Introduction

Inert gas narcosis is one of the challenges facing deep air divers, with the neuropsychological manifestations of nitrogen narcosis typically encountered from about 30 metres' sea water (msw).[1] Impairment of cognitive function attributed to nitrogen narcosis includes effects on concentration, choice reaction time, time estimation, visual scanning, memory and conceptual reasoning.[2–12] Dexterity appears the neuropsychological function least affected by mild nitrogen hyperbaric pressure.[3,5,11,13] Some studies have found no evidence that nitrogen narcosis at pressures within sport diving limits leads to significant psychomotor impairment on simple tasks.[3,11,13] Others have reported decreased manual dexterity at depth, which potentially could reduce a diver's ability to operate equipment and increase the risk for mistakes during emergencies.[2,4,6,11,14,15]

Apart from the general challenge of impaired neuropsychological functioning due to nitrogen narcosis at depth, commercial and military diving often takes place in low visibility. Divers thus may need to complete tasks that require the above neuropsychological functions but without the ability to see what they are doing. In a task-environment where visibility has deteriorated, individuals have to rely on tactile perception as a primary mode of data acquisition. To complete more complex tasks, they need to translate tactile information into three-dimensional mental images and solve problems mentally before translating them back into motor actions, with tactile sensation providing feedback. When these actions happen under hyperbaric conditions, factors like nitrogen narcosis could influence a person's ability to successfully complete such tasks.

A search of the available literature did not find any studies describing the effect of hyperbaric nitrogen on complex tactile performance. This study set out to examine: 1) the effect of hyperbaric nitrogen narcosis at a pressure of 608 kPa on tactile performance without visual access to the task, and 2) to investigate the influence of psychological and biographical factors on the above relationship.

Methods

STUDY DESIGN

The study employed a simple, prospective, cross-over design. Participants were randomly allocated to two subgroups. One group was studied first at 101.3 kPa, and then at 608 kPa (equivalent to 50 metres' sea water, msw), while the other group completed the two conditions in the reverse order. Ethics approval was obtained from the Stellenbosch University Health Research Ethics Committee (approval no: N11/06/176).

Table 1
Distribution of academic attainment, diving qualifications and technical work experience (%)

Academic achievement:	
Did not complete high school	9
High school certificate	56
Formal post-school vocational training	21
National diploma or university degree	14
Diving qualification:	
Class IV	49
Class III	32
Class II	19
Formal technical work experience:	
None	73
1 to 2 years	18
3 or more years	9

PARTICIPANTS

After written informed consent, a total of 139 commercial divers – as part of a larger study on the effects of nitrogen narcosis – completed the procedure in a dry pressure chamber, with participants breathing air and dressed in loose coveralls. The study included mainly younger divers (mean age 26.8 ± 5.9 years, range 18 to 44 years), mostly male (87%), and with little previous deep diving exposure. Their academic attainment, diving qualification, and formal technical work experience are presented in Table 1. The majority of the group had no formal technical qualifications (83.5%). Participants were also asked to self-rate their technical competence.

MEASURES

Tupperware Neuropsychological Task (TNT)

Tactile performance was measured using the Tupperware Neuropsychological Task (TNT). The TNT is based on the Tupperware™ *Shape O Toy*, which consists of a round ball that has 10 different shapes cut out of it, and 10 three-dimensional shapes that correspond to the cut-outs. The purpose is to fit the correct shapes into the cut-outs. To isolate any visual effects, the TNT was completed with the subject wearing a blacked-out facemask, without prior opportunity to see the ball or shapes. Participants' scores were the total number of shapes completed in 10 minutes.

The TNT incorporates the classical elements of performance sequencing, namely: 1) perception, 2) information processing and 3) motor response.[16] The TNT's association with the underlying constructs of tactile form perception, three-dimensional spatial perception and fine motor manipulation has been established earlier, and no significant correlations with age, education, anxiety or sex effects have been found.[17,18]

State-Trait Personality Inventory, Trait Anxiety (STPI)

Trait anxiety was measured with the STPI, Form Y.[19] The STPI is a self-administered questionnaire designed to measure dispositional anxiety in adults. The 10-item trait anxiety subscale was used in this study.[19]

Brunel Mood Scale (BRUMS)

Transient mood states (including state anxiety) were recorded with the BRUMS. It is a 24-item scale that measures six identifiable affective states through a self-report inventory. It taps the mood states of tension, depression, anger, vigour, fatigue and confusion.[20]

Biographical questionnaire (BQ)

A questionnaire recorded age, sex, formal education (academic, technical and diving qualifications) and technical proficiency (experience in formal technical work environments and self-graded technical competency). Age and education may affect the time to complete tactile performance tests,[21] and technical skills, through over-learning, may be particularly resistant to the effects of depth-induced narcosis.

STATISTICAL ANALYSIS

The effect of hyperbaric nitrogen at 608 kPa on TNT performance was analysed with a repeated measures ANOVA. The association of neuropsychological performance under hyperbaric conditions with psychological factors, age and self-rated technical competence was explored using correlational statistics. Its association with gender, qualifications and formal technical work experience was explored using Student's *t*-tests and one-way ANOVAs. Correlational statistics was also used to determine the interaction of surface performance and performance at depth.

Results

The STPI had a mean score of 16.4 ± 3.9, comparable to the scores in the manual. BRUMS scores represented the typical desired iceberg profile. There were no significant correlations with age, sex differences or differences between the two subgroups on either the STPI or the BRUMS. There was no violation of the assumption of sphericity. The TNT results are shown in Table 2 and Figure 1. Performance deteriorated significantly at depth compared to the surface, irrespective of the sequence of the dives (shallow/deep or deep/shallow), the mean decrement being 9.5%. Further, the order of the two pressure exposures did not show a statistically significant effect on TNT performance.

There was a significant correlation between TNT scores on the surface and at depth ($r = 0.71$, $P < 0.001$). Tactile performance on the surface appears a good predictor of

Table 2

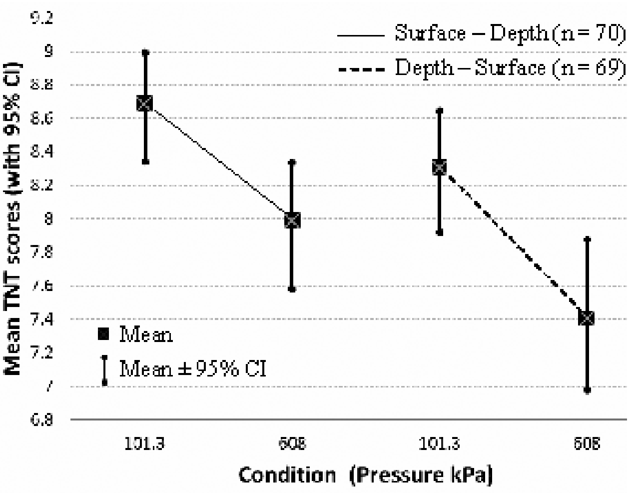
Tupperware Neuropsychological Task (TNT); results from repeated measures ANOVA; ηp² (partial eta squared) indicates effect size

	Wilk's Lambda	F	df	*P*	η_p^2
TNT Condition	0.683	63.694	1,137	0.001	0.317
Condition*Sequence	0.993	0.983	1,137	0.323	0.007

TNT [mean total (SD)]	Surface	Depth	*n*
Group 1 Surface – Depth	8.69 (1.37)	7.99 (1.58)	70
Group 2 Depth – Surface	8.30 (1.51)	7.41 (1.89)	69

Figure 1

Mean (95% confidence interval, CI) performance on the Tupperware Neuropsychological Task (TNT) by 139 divers at pressures of 101.3 kPa and 608 kPa with different sequences for the two dives



performance under hyperbaric pressure at 608 kPa.

No significant correlations between the STPI or BRUMS and performance at depth were found. Further, none of the biographical variables had any significant effect on performance.

Discussion

The decrement of performance on the TNT at depth was similar for all participants, independent of their psychological or biographical profile, indicating that any effects can be attributed to nitrogen narcosis alone. Since motor dexterity is considered less affected by narcosis than other aspects of neuropsychological performance, impairment of performance on the TNT could probably be attributed to the cognitive processing of tactile performance. The results obtained with the TNT are consistent with predictions from the slowed processing model.[22]

The TNT is a complex task, requiring tactile perception, mental translation and manipulation, planning and psychomotor execution, with feedback and then a repeat of the process. This task complexity makes it particularly susceptible to the cumulative effects of slowed information processing. In the light of the performance sequencing referred to earlier, the consequences of slower task completion would hold true for many underwater tasks in the commercial diving industry.

It has been demonstrated that elevated anxiety may have a significant effect on manual dexterity, quite separate from any narcotic effect.[14,15] Anxiety exacerbates the effects of narcosis, and especially the impairment of psychomotor functioning.[6,15,23,24] The anxiety effects reported in previous studies were not replicated here.[14,15,23] This may in part be due to both the sample composition and the diving environment.

Firstly, previous studies generally used sport divers, whereas the present study used commercial divers. It is hypothesised that more individuals with high anxiety would self-select out of commercial diving. There is support for this from the present sample, in the form of the small range of anxiety scores, clustered on the lower end of the scales of both trait and state anxiety measures (data not shown). Secondly, the study took place in a dry hyperbaric chamber, generally regarded as a low-threat environment considered not to have the anxiety-provoking effect of the open water.[27]

Environmental (open water, temperature) and individual (psychological and biographical) factors further influence the relationship between performance and narcosis. The effect of narcosis on performance is greater under wet than dry conditions.[23] Inside a hyperbaric chamber, the psychological stressors of ocean diving are absent, as well as the muscular strain and environmental conditions (buoyancy, temperature) encountered there.[26] Open water further elicits performance interference from the water effect, i.e., movement in a viscous medium and the buoyancy effects in a tractionless setting that affects the use of tools, as well as anxiety around potential dangers.[16]

Thus, results from protected environments cannot always be transferred directly to open-water conditions.[23] It is generally accepted that the greater effect of nitrogen narcosis in the open water, relative to hyperbaric chambers, can largely be attributed to increased anxiety.[14] It is recognised that results from dry chambers cannot be transferred directly to open-water conditions.[23,26] Thus, the hyperbaric nitrogen effect found in this study would most likely be amplified in an open-water situation.

The most severe stress in diving is cold exposure. The relationship between cold-water exposure and performance on tasks involving tactile sensitivity, grip strength, and finger dexterity has been well established, with divers' tactile sensitivity decreasing linearly with decreased finger skin temperature at 40 msw.[16,27] While cold itself adversely affects performance, protective measures (e.g., gloves) limit tactile sensation and fine manual manipulation even further.[16]

Although there is no evidence available that age, sex, formal education or previous technical exposure play any significant role in moderating the effect of hyperbaric nitrogen, it can be hypothesised that formal exposure, through a process of over-learning of principles or practices, might protect against impaired performance in tasks requiring technical reasoning or manual dexterity. The absence of reported evidence that age, training or formal technical work play a role in moderating the effects of nitrogen narcosis was maintained in this study. As with previous studies, no gender effect of nitrogen narcosis on performance has been found, although women formed only a small proportion of the sample.[28] However, the variation within this sample on the psychological and biographical markers was very small, and it cannot be concluded that these variables would not influence performance in other samples.

Future studies could attempt to replicate the effects on tactile performance in open-water conditions, with the added considerations of muscular strain (and associated tactile sensations), buoyancy, water viscosity, and temperature and associated protective clothing. Further, future studies need to explore the role of tactile and psychomotor practice effects, particularly the optimal amount of rehearsal required to counter the effects of hyperbaric nitrogen. This needs to be done on land (where practice in reality will generally take place), and in shallow water, to explore the practice effects of not only the number of repetitions, but also of the environment.

Conclusions

A complex neuropsychological task requiring tactile input (the Tupperware Neuropsychological Task), performed without visual aid, was impaired by a mean of 9.5% at 608 kPa in a dry pressure chamber compared with 101.3 kPa. These findings have important practical implications for professional divers in both the commercial and military diving industries, where conditions of low visibility during deeper diving typically occur. To compensate for this, divers would benefit by firstly planning more time to complete complex tasks (especially in low visibility), and secondly by practicing those tasks prior to the actual deep dive, either on the surface or in shallow water. In this regard, 'blind' performance on the surface was a good predictor of blind performance at depth. Pre-dive practical learning (rehearsal) as an aide to successful completion of that task may be helpful, especially with more complex tasks.

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Charles H van Wijk and Willem AJ Meintjes, Division of Community Health, Faculty of Medicine and Health Sciences, Stellenbosch University, South Africa

Address for correspondence:
Charles van Wijk
PO Box 494
Simon's Town, 7995
South Africa
Phone: *+279-(0)21-782-7030*
E-mail: *<chvanwijk@gmail.com>*
