Subjective and behavioural responses to Nitrogen Narcosis and Alcohol.

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Hobbs M. Subjective and behavioural responses to Nitrogen Narcosis and Alcohol. Undersea Hyperb Med; 35(3):175-184. Rationale: There is a widespread assumption that nitrogen narcosis is comparable to alcohol intoxication, a similarity that may extend to patterns of tolerance. It has been suggested this indicates evidence of a shared biological mechanism but there is a paucity of experimental data to support these claims. Objective: The current study aimed to test this assumption by comparing subjective (ratings) and behavioural (Digit Letter Substitution Test) responses to nitrogen narcosis and alcohol. Methods: Experiment 1 compared responses to narcosis in 39 participants posited to differ in tolerance based on prior exposure to alcohol (heavy/light drinkers) and narcosis (novice/experienced divers). Experiment 2 compared responses to narcosis and after a 0.5g/kg dose of alcohol in 23 participants. In both experiments narcosis was measured at depths between 40 and 45m in the ocean off Port Vila, Vanuatu. Results: Experiment 1 measured a significant decrement in the behavioural measure underwater, compared to baseline but failed to find any differential responding to narcosis between drinker or diving experience groups. In contrast, Experiment 2 found positive correlations between alcohol and narcosis on both subjective and behavioural measures, indicating those affected to a greater degree by alcohol were also affected to a greater degree by narcosis. Conclusions: These results support the contention of a relationship between nitrogen narcosis and alcohol, although the role of diving and drinking history, if any, remains obscure.

INTRODUCTION

Nitrogen narcosis is a phenomenon that occurs when exposed to increased partial pressures of nitrogen. Most commonly seen in undersea divers, it is considered a significant contributing factor in diving related accidents (1). Narcosis is characterised by an impairment of psychomotor coordination and alterations in mood and behaviour. The consensus is that symptoms can become apparent at a depth of 30m and increase with further increases in depth (2). Alterations in mood can be positive (e.g. feelings of euphoria, lowering of inhibitions) or negative (e.g. increases in anxiety, impairment of reasoning ability), with considerable inter-individual variability in symptom type, onset and severity. Many of these symptoms are shared during alcohol intoxication which is also characterised by progressive psychomotor impairment and similar alterations in mood and behaviour. This similarity has lead training organisations (3, 4) to universally encourage student divers to view nitrogen narcosis as comparable to being ‘drunk’.

The similarity in symptoms may extend to other characteristics. It is well established (5, 6) that repeated exposure to alcohol results in tolerance to some of its effects and there is a belief in the diving community (3) that tolerance also develops to narcosis. Unfortunately, the experimental evidence is less clear. Some...
studies report impairment from nitrogen narcosis decreases after continued exposure at depth (7) or with repeated exposures to narcosis (8), whereas others have failed to find any evidence of a reduction in impairment (9, 10). More recently, Hamilton et al (11, 12) have suggested the mixed evidence is a result of tolerance developing to the subjective but not the behavioural component of narcosis. They measured decrements in reaction time and subjective measures at 54.6m in a hyperbaric chamber. After five exposures, decrements in reaction time had not improved but overall estimates of narcosis and subjective ratings related to bodily sensations (‘dreamy’, ‘light-headed’, ‘intoxicated’) decreased significantly from the third exposure. A similar pattern in responses to alcohol has been reported by comparing heavy and light drinkers (13, 14). Heavy drinkers, presumed more tolerant to alcohol as a result of greater prior exposure, differed from light drinkers on subjective measures to alcohol but not behavioural measures of psychomotor impairment.

Despite the apparent similarities there has been an extraordinary lack of evidence to support the widespread assumption that narcosis is comparable to alcohol. In fact, only one pilot study, by Monteiro et al (15), has directly compared the effects of alcohol and nitrogen. In this study 14 divers took part in two sessions. In one session they received a 0.6g/kg dose of alcohol and completed the Subjective High Assessment Scale (SHAS), a 12-item subjective rating scale for measuring drug effects. In another session they underwent a simulated dive to 50m in a hyperbaric chamber. On the simulated dive they again completed the SHAS. Significant positive correlations were found for some items from the SHAS (‘high’, ‘anxious’, ‘light head’, ‘difficulty concentrating’) between the simulated dive and the alcohol session. This suggested that those people who were affected to a greater degree by the alcohol were also affected to a greater degree by nitrogen narcosis. In addition, the responses of sons of alcoholics and sons of non-alcoholics were compared, with a trend towards the sons of alcoholics reporting less intense feelings of narcosis compared to the sons of non-alcoholics. The authors speculated that this was because the sons of alcoholics had an innate tolerance to alcohol which is transferable to narcosis and suggested that this relationship between alcohol and narcosis reflected some common neurobiological basis between the two.

The current research aimed to explore further the claimed relationship between alcohol and narcosis. Experiment 1 was designed to compared responses to narcosis in groups that would be expected to differ in tolerance, as a result of prior exposure, to either alcohol (heavy/light drinkers) or narcosis (novice/experienced divers). If narcosis and alcohol share a common neurobiological basis and tolerance does indeed develop to narcosis, transference of tolerance from one to the other might be expected. Thus it was predicted that heavy drinkers and experienced divers would be less affected by narcosis than light drinkers and novice divers. In light of the proposed dissociation in tolerance to narcosis by Hamilton et al, the current study used both subjective and behavioural measures of narcosis. Experiment 2 was designed to extend the research by Monteiro et al by replicating their study, but with nitrogen narcosis measured in an underwater environment and with the inclusion of an extra behavioural measure. It was predicted that individuals affected to a greater degree by nitrogen narcosis would also be affected to a greater degree by alcohol.
EXPERIMENT 1: NARCOSIS IN HEAVY/LIGHT DRINKERS AND NOVICE/EXPERIENCED DIVERS

METHOD

Design
The experiment used a 2 x 2 x 2 mixed ANOVA design. There were two between-groups factors of drinker status (heavy vs. light) and diving experience (novice vs. experienced) and a within-groups factor of testing session (baseline vs. underwater). A behavioural measure of psychomotor performance was measured in both baseline and underwater sessions and subjective ratings were measured during the underwater session. The order of the baseline and underwater sessions was counterbalanced to control for learning effects.

Materials and Environmental Conditions
Alcohol consumption was measured using Mehrabin and Russell’s (16) Habitual Alcohol Use Questionnaire (HAUQ), a 12-item self-report questionnaire on typical volume consumed, rate of consumption, and frequency of excess alcohol consumption. A formula yields a single score representing the habitual alcohol consumption of each participant. The current study included an extra question for participant’s to report the number of dives they had completed in the last six months.

The behavioural measure of psychomotor performance was the Digit Letter Substitution Test (DLST), a variant of the Digit Symbol Substitution Test (17). The DLST requires participants to convert digits (1 to 9) to letters (N, K, Z, V, P, H, S, C, and Q). Scores are derived by counting the number of digits correctly converted within one minute. Two versions were used (baseline and underwater), using the same letters but with differing corresponding digits to control for the effects of learning.

Subjective measures were obtained using a modified version of the SHAS. Participants were asked to provide a rating between 0 and 100 (0 = Not at all, 50 = moderately, 100 = extremely) as to how they felt at that moment for 11 adjectives: ‘Uncomfortable’, ‘High’, ‘Anxious’, ‘Nausea’, ‘Weak’, ‘Tense’, ‘Difficulty concentrating’, ‘Elated’, ‘Confused’, ‘Dizzy’ and ‘Light head’. The SHAS usually includes the adjective ‘sweating’, which was not deemed appropriate for an underwater environment and was replaced with the adjective ‘intoxicated’.

All dives were completed from Port Vila, Vanuatu. Conditions were very stable with a consistent water temperature of 27-28 degrees Celsius, visibility between 15 and 30 metres on every dive and no noticeable current. All participants were diving on normal air from the same compressor and were guided by the researcher.

Participants
Thirty-nine participants (24 males; 15 females) aged between 18 and 55 years (Mean = 33.3; SD = 9.6), volunteered for the study. All participants were customers at Nautilus Watersports in Port Vila, Vanuatu and volunteered to take part in the study during dives they had decided to complete for pleasure or as part of a training course before recruitment for the study. An established screening process was conducted by Nautilus which fulfilled the requirements of the ethical committee of the Department of Psychology at the University of Winchester and confirmed that participants were suitably qualified and medically fit to dive to the depths required for the study.

Participants were assigned novice or experienced diver status by conducting a median split for the number of dives they had completed in the last six months. The last six months was used as many participants had dived
irregularly, with long periods of abstinence, and the use of long term evaluations (e.g. years of diving) would have exaggerated their experience level. The resulting novice diver group had completed a mean of 8.1 dives in the last six months (SD = 5.2; range 1-18) and the experienced diver group a mean of 91 dives (SD = 86.2; range 20-300).

Participants were assigned heavy or light drinker status by conducting a separate median split for each gender on the basis of their scores on the HAUQ. Separate splits are appropriate because it avoids a preponderance of males in the heavy drinker group due to gender differences in the effects of alcohol and drinking practices (cf. 18, 19). The resulting light drinker group had a mean score of 12.9 points (SD = 6.6; range 0–23.9) and the heavy drinker group a mean score of 49.4 points (SD = 25.5; range 22.8-109). There were 11 novice and 9 experienced divers in the light drinker group. In the Heavy drinker group there were 8 novice and 11 experienced divers.

Procedure and Data Analysis

All participants completed two sessions, one on the surface and one underwater. During the surface session participants completed the HAUQ and the baseline DSLT. During the underwater session the researcher guided participants in groups of no more than four to an appropriate space on the ocean floor at a depth between 40 and 45m (Mean = 42.4; SD = 1.7). Descent time was between three and 10 minutes, dependent on the dive site. Participants then knelt on the ocean floor and as soon as they were comfortable completed the SHAS and the underwater version of the DLST on an underwater slate. Participants then completed the remainder of their planned dive and were fully debriefed once back on the surface. The data was analysed using analysis of variance. An alpha value of 0.05 was used as the criterion of significance in both studies reported here. The order of the sessions did not affect any of the measures and will not be discussed further.

RESULTS

Behavioural Measure (DLST)

The results, shown in Figure 1, show a clear overall decrement on performance on the DLST between the baseline and underwater conditions, with a mean overall decrement of 14.2% (SD = 12.8). There was no clear evidence of a difference between heavy/light drinkers and novice/experienced divers. This was confirmed by a three-way ANOVA (testing session x drinker status x diving experience) which found a significant main effect of testing session [F(1, 35) = 35.84], indicating an effect of narcosis was measured, but no effect of drinker status, diving experience and no significant interactions (all Fs <1.82).

Subjective Measure (SHAS)

A series of two-way ANOVAs (drinker status x diving experience) found significant effects of diving experience for ‘anxious’ [F(1, 35) = 4.83] and ‘tense’ [F(1, 35) = 6.18]. In both cases the novice divers gave higher ratings than the experienced divers, indicating higher

![Fig. 1. Mean (+SD) baseline and underwater DLST scores for heavy/light and novice/experienced divers.](http://archive.rubicon-foundation.org)
levels of anxiety and tension. There was also
a near significant effect of diving experience
for ‘difficulty concentrating’ [F(1, 35) = 3.33],
with a trend towards the novice divers giving
higher ratings than the experienced divers. A
significant effect of drinker status was found for
‘weak’ [F(1, 35) = 4.6], with the light drinkers
reporting they felt weaker than the heavy
drinkers. A near significant effect of drinker
status was found for ‘nausea’ [F(1, 35) = 3.8,
p<.06], with a trend towards light drinkers
reporting more nausea than heavy drinkers.
There were no significant effects of drinker status
or diving experience for any of the other ratings
and no significant interactions (all Fs<1.4).

EXPERIMENT 2: CORRELATION
BETWEEN EFFECTS OF NITROGEN
NARCOSIS AND ALCOHOL

METHOD

Design
All participants had completed
Experiment 1 prior to participation in Experiment
2. Experiment 2 measured subjective (SHAS)
and behavioural (DLST) responses to a 0.5g/kg
challenge dose of alcohol. This data was then
combined with the subjective and behavioural
data from Experiment 1, allowing comparisons
on the basis of a three level within-groups factor
of testing session (baseline vs. underwater vs.
alcohol). Drinker status and diving experience
were not analysed in this experiment as the
sample size was considered too small.

Participants and Materials
Twenty-three participants (12 males; 11 females) aged between 23 and 55 years (Mean = 32.8; SD = 8.7) volunteered for the
study. To fulfil University ethical requirements,
participants were only admitted if they weighed at least 60kg and were accustomed
to consuming the amounts of alcohol used in
the experiment, determined by a self-report
questionnaire of alcohol consumption in the
last week. Participants were required to have consumed at least 10 UK standard units in
the past week¹. The 0.5g/kg challenge dose of
alcohol was presented as beer (Tusker 5%),
Gin (40%) or Vodka (40%) dependent on the
participant’s preference, to ensure that the
dose could be consumed comfortably. The
subjective and behavioural measures utilised
the same versions of the SHAS and DLST as
used in Experiment 1. Although the same DLST
was used the corresponding digits/letters were
different from the baseline and underwater
versions to control for learning effects.

Procedure and Data Analysis
Participants were given the option
to take part in Experiment 2 when they were
recruited for Experiment 1. They were advised
not to take part in any activities that may be
dangerous under the influence of alcohol for
the remainder of the day after taking part in
the experiment and to remain with the researcher
for an hour after completion. If they chose not to
stay with the researcher they signed a disclaimer
saying that they took full responsibility for their
actions. Participants were weighed at the start
of Experiment 2 and made fully aware, before
they had consumed any alcohol, of the volume
of alcohol they would be given. A 0.5g/kg
challenge dose of alcohol was then presented.
Participants were instructed to consume the dose
within 20-30 minutes. Fifteen minutes after the
dose had been consumed the alcohol version of
the DLST and the SHAS were administered.
All participants were fully debriefed at the end
of the study. The data for the DLST and SHAS
were analysed separately. The DLST scores
were analysed using analysis of variance in
order to assess overall performance in the
baseline, underwater and alcohol sessions. The
scores for the underwater and alcohol sessions
were then converted into % change from

¹ The amount of alcohol used in the experiment was determined by a self-report questionnaire of alcohol consumption in the
last week.
baseline and a Pearson’s correlation coefficient calculated. Converting the scores normalised them for individual baseline differences in ability on the DLST, ensuring the correlation was measuring a legitimate relationship between the alcohol and underwater sessions rather than simply ability on the DLST. The SHAS was analysed by calculating a Pearson’s correlation coefficient for each set of ratings between the underwater and alcohol sessions.

RESULTS

Behavioural measure (DLST)

Table 1, below, shows the mean DLST scores for the baseline, underwater and alcohol testing sessions. Scores in both the underwater and alcohol sessions were lower compared to the baseline score but were similar for each other. This was confirmed by a one-way repeated measures ANOVA, which indicated a significant effect of *testing session* \[F(1, 22) = 14.2\]. Follow-up t-tests indicated that the scores on the alcohol \[t(22) = 3.7\] and underwater \[t(22) = 4.2\] sessions were significantly lower compared to the baseline session but not to each other \[t(22) = 1.6\], indicating effects of nitrogen narcosis and alcohol on performance. Figure 2 shows a scatter plot for % change from baseline scores for the underwater and alcohol sessions. Minus values reflect when participants scored better than their baseline scores (5 scored better underwater; 7 scored better or the same after alcohol). Figure 2 suggests that individuals that showed greater performance decrements underwater were more likely to show greater decrements after alcohol. This was confirmed by a significant positive correlation \[(r = 0.41)\] for the % change from baseline scores between the underwater and alcohol sessions.

![Fig. 2. DLST scores as % change from baseline underwater and after alcohol](http://archive.rubicon-foundation.org)

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<tr>
<th>Subjective ratings (SHAS)</th>
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Table 2, opposite page shows the mean scores and correlation coefficients for each of the items on the SHAS in response to alcohol and underwater. Most of the ratings were higher after alcohol compared to underwater. Significant positive correlations were found between the underwater and alcohol conditions for 4 out of 12 adjectives (‘confused’, ‘weak’, ‘intoxicated’ and ‘difficulty concentrating’), indicating that on these measures individuals affected to a greater degree after alcohol were also affected to a greater degree by nitrogen narcosis.

<table>
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<tr>
<th>Table 1. Mean DLST score (SD) and t-test results for baseline, underwater and alcohol sessions</th>
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*Note.* n.s = not significant
DISCUSSION

Experiment 1 demonstrated a significant decrease on psychomotor performance underwater, indicating some impairment from nitrogen narcosis, but this impairment did not differ between heavy and light drinkers or novice and experienced divers. Several significant effects were found for the subjective measures between novice and experienced divers (‘anxious’; ‘tense’) and light and heavy drinkers (‘weak’). This differential effect of diving experience on the subjective but not behavioural measure would, initially, appear to support Hamilton et al (11, 12) claim of a dissociation between the subjective and behavioural components of narcosis. Hamilton et al reported measures relating to bodily sensations (‘light headed’; ‘dreamy’; ‘intoxicated’) and a global estimate of narcosis as those reduced by repeated exposure to narcosis. In the current study, measures relating to bodily sensations (‘light head’; ‘dizzy’; ‘intoxicated’) were no different between novice and experienced divers. Instead the differences were on ratings related to anxiety and tension. While increases in anxiety can be symptomatic of narcosis, the difference here may just as likely reflect anxiety caused by the mere fact of doing a deep dive, a daunting prospect for most novice divers, rather than an actual difference in narcosis. Likewise, the difference between the heavy and light drinkers for the ‘weak’ ratings is unlikely to be related to narcosis. As the drinker groups did not differ on the adjectives (e.g. ‘intoxicated’; ‘high’; ‘light head’; ‘confused’) that might be thought more relevant to narcosis, it is not possible to consider this effect as indicative of a difference in the experience of narcosis. Experiment 1, therefore, does not support the prediction that experienced divers and heavy drinkers would be less affected by narcosis than novice divers and light drinkers.

In contrast, the results for Experiment 2 demonstrated a relationship between psychomotor performance underwater and after alcohol. In addition, multiple subjective ratings (‘confused’; ‘weak’; ‘intoxicated’; ‘difficulty concentrating’) showed a positive correlation. These results concur and extend those of Monteiro et al (15) and suggest that those affected to a greater degree by nitrogen narcosis are affected to a greater degree by alcohol on both subjective and behavioural measures. There were differences on the adjectives that correlated in the Monteiro et al study (‘high’; ‘anxious’; ‘light head’; ‘difficulty concentrating’) and those in the current study. This difference should not be regarded as critical to the findings and may reflect the small sample size in the Monteiro et al study or differences between the hyperbaric and underwater environments.

It is not possible to determine exactly what this relationship reflects from the current study, although Monteiro et al provided one explanation. They suggested that the relationship they observed between alcohol and narcosis reflected an overlap in the neurobiological systems alcohol and nitrogen impact upon.
Alcohol and nitrogen impact on myriad neural systems, some of them the same. For example both alcohol and increases in nitrogen pressure have been shown to affect dopamine (20, 21, 22) and gamma-aminobutyric acid (GABA) systems (23, 24, 25). Monteiro et al’s concept is, therefore, not unreasonable but currently lacks evidence and requires further assessment. Additionally, Monteiro et al’s explanation should be treated with caution in light of the fact that, despite some similarity in signs and symptoms, alcohol and narcosis also have a numerous differences. For example, Bennett and Rostain (2) point out that at extreme depths (>100m) the symptoms of narcosis are closer to anaesthetics or “more typical of those due to psychedelic drugs…rather than alcohol”. The finding of a relationship between alcohol and narcosis may therefore reflect other factors, such as ability to manage intoxication, rather than similarity of neurobiological impact.

Experiment 1 and 2 offer conflicting conclusions on the relationship between narcosis and alcohol. The differences might be reconciled by consideration of the sensitivity of some of the measures employed. The correlation between the psychomotor measures was only moderate and the method of assigning novice/experienced diver status may not have been sufficiently sensitive to pick up anything less than a strong relationship. Although any increase in pressure causes an increase in nitrogen in the body, and there is limited evidence of a subtle form of narcosis in shallow water (28), it is not unreasonable to assume that any development of tolerance to narcosis would require dives sufficiently deep for clear effects of narcosis to become apparent. The assignment of novice/experienced diving status based on number of dives may have missed an effect of experience as it takes no account of the depth of those dives and despite the experienced divers having completed a large number of dives many had little experience over 35m. Thus, assigning experience level based on actual deep dive experience may be more appropriate. Additionally, most of the hyperbaric studies cited used equivalent pressures of 50m+. The subjective effects of narcosis around 40m are usually mild and clearer results may be gained from studying responses deeper than those used in this study as any differences between groups might be easier to measure if the sensations of narcosis are more obvious to the participant.

Similarly, if a moderate relationship between narcosis and alcohol is posited the failure of an effect of drinker group in this study may have resulted if the participants did not differ sufficiently in drinking practices. The amount of alcohol consumed in the past week by the light (8.4 units; SD = 8.0) and heavy drinkers (33 units; SD = 18.6) suggests most of them were moderate social drinkers when compared to clinical samples. It may therefore be appropriate to compare populations that differ more dramatically in their drinking practices. Alternatively, a superior method would be to employ actual laboratory measures of tolerance to precisely identify individuals that differ in tolerance to alcohol, rather than drinking practices which merely assume some difference exists as a result of prior exposure.

Hyperbaric studies have the advantage of providing a highly controlled environment where decrements in performance can reliably be attributed to nitrogen narcosis but it remains important to replicate findings from hyperbaric studies in real-life underwater scenarios. Open water studies are necessarily less controlled and other factors associated with the underwater environment, such as cold (29), anxiety (30) and current impact on performance. Thus, it could be countered that the decrement in psychomotor performance in this study was the result primarily, not of narcosis, but factors associated with the underwater environment. However, the conditions in this study were exceptional with good visibility, no current,
warm water and unlikely to have impacted significantly on performance. An unpublished pilot in shallow water (under 10m) in the same conditions also found no difference in performance from baseline. In addition, if environmental factors were responsible for the decrement this result would be hard to reconcile with the correlation with performance after alcohol. While the role of other factors should not be completely discounted it is felt that the underwater decrements in this study were the result of narcosis.

In conclusion, the current study supports the contention of a relationship between the effects of alcohol and nitrogen narcosis, although the nature of this relationship cannot be determined at present and the role of diving and drinking history remains an open question.

ACKNOWLEDGMENTS

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