An unblinded training exposure to hypoxia enhances subsequent hypoxia awareness

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Abstract
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Introduction: Malfunctions and human errors in diving rebreathers can cause hypoxia, hyperoxia, and/or hypercapnia. We evaluated whether a prior unblinded hypoxia experience enhances a diver's ability to recognise hypoxia and initiate self-rescue.
Methods: Forty participants were randomised to receive either an information leaflet describing hypoxia symptoms or an unblinded hypoxia experience, prior to a blinded hypoxia testing exposure during a virtual reality dive over one month later. The primary outcome was the comparison of the proportion of participants in these two groups who initiated self-rescue before reaching a peripheral oxygen saturation of 70% in the blinded exposure. An individual's 'symptom profile' was assessed by comparing symptoms during the unblinded hypoxia experience and blinded testing exposures.
Results: During the blinded hypoxia testing exposure, 18/20 (90%) participants in the hypoxia experience group performed a self-initiated rescue compared to 6/18 (33%) in the information leaflet group ($P < 0.001$). Participants in the information leaflet group had lower mean SpO_2 (73.4% vs 81.4%, mean difference 8% [95% CI = 2.5–13.5%, $P = 0.005$]) and lower inhaled oxygen fraction (7.6% vs 9.4%, mean difference 1.8% [95% CI = 0.6–3.1%, $P = 0.005$]) at self-rescue. The most frequent and severe symptoms were light-headedness and shortness of breath. Of the 20 participants completing both hypoxia exposures, 14 (70%) had a consistent hypoxia symptom profile, which was not related to the ability to recognise hypoxia.
Conclusions: Self-rescue was approximately three times more likely for participants who had previously experienced hypoxia compared to simply receiving information on relevant symptoms. Most participants exhibited a consistent pattern of individual symptoms, which did not result in earlier or improved detection of hypoxia.

Introduction

Rebreathers are used in scientific, military, and recreational diving. Closed circuit rebreathers have numerous advantages over traditional open circuit scuba equipment, such as extending the duration of a gas supply, preserving expensive gases (e.g., helium), minimising exhaled bubbles, and providing warm, humidified breathing gas. Breathing gas is recycled in a rebreather by removing carbon dioxide and adding oxygen. Failure to perform these functions can lead to hypercapnia, hypoxia, or hyperoxia (referred to as 'the 3-H's'), which may, in turn, cause incapacitation, unconsciousness, and drowning. Two-thirds of military rebreather accidents[1] and more than a third of the recreational rebreather fatalities have been attributed to the 3-Hs.[2]

To combat these hazards, rebreather divers typically carry an independent supply of open-circuit bailout gas. However, bailout gas is only useful if the diver can recognise the need and maintain sufficient cognitive and motor functions to transfer gas supply during the 'bailout' process. Hypoxia is challenging to detect and manage because it can quickly impair cognitive abilities before a diver can initiate self-rescue using their bailout gas.[3,4] Hypoxic people underestimated their degree of impairment despite making errors or becoming unresponsive.[5]

Many aviators undergo a controlled exposure to hypoxia by breathing air at a simulated high altitude in a hypobaric chamber.[6–8] Studies of this training practice have established that there are commonalities of hypoxic symptom experiences at group level.[6–8] It has been assumed that knowledge of one's 'hypoxic symptom signature' could facilitate early recognition and self-rescue in a future hypoxic event. There has been advocacy for such training in divers. However, no study to date has explicitly evaluated the effect of these periodic hypoxia 'training' exposures on the ability to self-rescue in a subsequent hypoxia exposure. This study investigated whether an unblinded hypoxia experience enhances a diver's ability to recognise hypoxia symptoms and initiate self-rescue in a subsequent blinded hypoxia exposure.

Methods

The study protocol was approved by the Health and Disability Ethics Committee, Auckland, New Zealand (reference 21/NTB/102), and was registered with the Australian New Zealand Clinical Trial Registry (U1111-1266-1320, http://www.anzctr.org.au/, RRID:SCR_002967).

PARTICIPANTS

This single-blind randomised study was conducted at the Exercise Physiology Laboratory at the University of Auckland between May and December 2023. Forty healthy participants aged 18 to 55 years old were recruited. Eligible participants were certified divers and deemed medically fit by the Recreational Scuba Training Council screening questionnaire. People currently using psychoactive drugs, tobacco, more than 21 alcoholic drinks per week or five caffeinated drinks per day, having a mental illness or prior hypoxia experience were excluded. At each visit, a physician confirmed medical fitness. All participants provided written informed consent.

STUDY DESIGN

Participants were block-randomised in REDCap[9] into 'hypoxia information leaflet' and 'hypoxia experience' groups. Participants in the hypoxia information leaflet group received a leaflet explaining the basic physiology of hypoxia and the most common symptoms presented in a manner consistent with commonly available diver educational material (*Appendix 1). Participants in the hypoxia experience group received the information leaflet plus an unblinded / open-label hypoxia experience as described below (Figure 1).

The blinded 'hypoxia testing exposure' undertaken by both groups was scheduled no sooner than four weeks after the hypoxia experience. In this testing exposure participants were told that they may be exposed to hypoxia or normoxia on a randomised basis but that we would not tell them which exposure they were receiving. However, since our primary outcome was a comparison of the recognition and self-rescue performance of the two groups when exposed to hypoxia, and to increase the power of the study, with ethics approval, all participants were exposed to hypoxia. After the study was complete, participants were debriefed on the fact that they were all exposed to hypoxia in the testing exposure, and they provided additional informed consent for the use of their data.

EQUIPMENT CONFIGURATION

A closed-loop breathing circuit was built from an O_2ptima closed-circuit rebreather (Dive Rite, Lake City, USA), Inspiration and Sentinel bailout valves (AP diving, Helston, UK and VR Technology, Poole, UK) and AD Instrument parts (Dunedin, New Zealand) (Figure 2). Participants breathed through a mouthpiece with a disposable filter attached to a bailout valve. The bailout valve was connected with respiratory tubing (MLA1011A, AD Instruments) to the counter lungs via a 3-way manual stopcock (SP0143, AD Instruments). Both stopcocks could be opened to room air via a respiratory tube with a filter to simulate the breathing resistance of an intact rebreather circuit. The rebreather incorporated a canister containing Sofnolime® 797 (Molecular Products, Harlow, UK) to remove carbon dioxide. The automatic diluent valve was connected to an air cylinder. To produce hypoxia, normal oxygen additions were discontinued, resulting in a gradual decline in inspired oxygen levels similar to a real-world diving scenario with oxygen delivery failure. Oxygen was added at the mouthpiece to 'rescue' participants at the end of their exposures. In the hypoxia testing exposure, the Sentinel bailout valve was connected to 100% oxygen, which participants breathed if they self-rescued by turning the lever a quarter-turn.

A sampling line ported in the mouthpiece continuously measured inspired oxygen with a respiratory gas analyser (ML206, AD Instruments). Participants wore a 5-lead electrocardiogram and a finger peripheral oxygen saturation (SpO_2) sensor (Masimo Radical 7 Oximeter, CA, USA), known for its accuracy at low SpO_2 values.[10] All audible signals were silenced. All data were sampled continuously at 1 kHz using Powerlab 16/35 and acquired via LabChart Pro 8.1.24 (AD Instruments, Dunedin, New Zealand).

EXPERIMENTAL PROCEDURE

In both the experience and testing exposures participants were comfortably seated and wore a nose clip whilst breathing on the experimental set-up. Prior to each exposure, the breathing circuit was flushed with air to a near approximation of a standard volume. Each exposure

***Footnote:** Supplementary Appendix 1 is available to download from: https://www.dhmjournal.com/index.php/journals?id=358

Figure 1
Flow diagram of study design; note that numbers represent the plan, whereas due to technical issues, two participants were lost for analysis from the hypoxia information leaflet group. All participants were blinded to the intervention (hypoxia) during testing visits

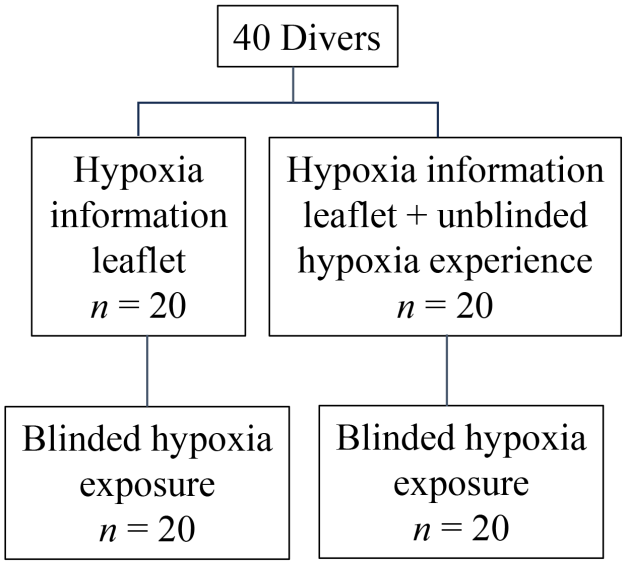
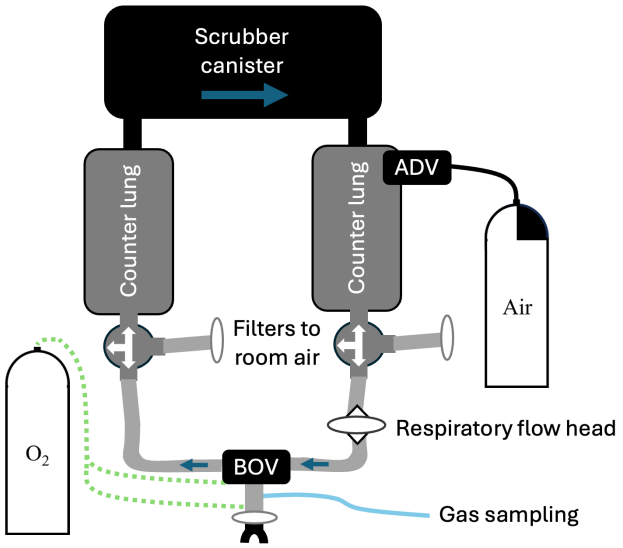


Figure 2
Experimental hypoxia rebreathing circuit set-up; the three headed arrows represent the 3-way manual stopcocks that allowed the switch between rebreathing circuit (depicted) and breathing room air (turn counter clockwise); ADV – automatic diluent addition valve; BOV – bailout valve



began with the participant breathing room air (circuit open to air) for two minutes, after which the circuit would be closed without the participants' knowledge, and the inspired fraction of oxygen and peripheral oxygen saturation would gradually decline. An anaesthetist was present during all hypoxia experience and testing exposures. At exposure termination, the breathing circuit was flushed with 100% oxygen until the participant's SpO_2 stably read > 99%.

Unblinded (open-label) hypoxia experience exposure

Cognitive functioning was monitored via a card recognition task adapted from our prior hypoxia study.[5] Playing cards between four and 10 (inclusive) of all four suits with the numbers removed were presented to the participant on a computer monitor, with one card appearing every six seconds. Participants identified the card by pointing to the corresponding card on an answer board depicting the number and suit. Participants were familiarised with the task, and their ability to achieve 100% task reliability was confirmed prior to the hypoxia experience training. Incorrect cards or failure to answer within 6 seconds were scored as errors. Based on previous work,[5] the termination criteria for the hypoxia experience were: (1) three errors made at any SpO_2, (2) two errors at SpO_2 < 60%, or (3) termination at the discretion of the physician (whichever occurred first).

Blinded hypoxia testing exposure

Participants were shown a standardised briefing video explaining the hypoxia testing exposure. Participants were 'immersed' in a virtual reality (VR) diving environment (HTC Vive Pro Eye, Taoyuan, Taiwan) and performed a distracting task of pushing a button every time an orca was sighted. They were instructed to bail out if they perceived hypoxia symptoms. The VR environment included a heads-up display with a green light at the bottom right of the visual field. If the participant's SpO_2 dropped below 70% without them attempting to bailout, the heads-up display would switch to red, to signal them to perform a bailout. If the participant failed to respond to the red signal, the rescue procedure was performed by the researchers.

OUTCOME MEASURES

The primary outcome measure was the proportion of participants who performed a self-initiated bailout during the blinded hypoxia testing exposure either prior to activation of the heads-up display or in response to it. Secondary outcome measures included SpO_2, inspired oxygen, elapsed time, and self-reported symptoms. Five minutes after each hypoxia exposure, participants were asked to recall the total number of errors they made and to rate the severity of these symptoms on a visual analogue scale (VAS) from 0 to 100. In an open-ended question, participants were asked what their first recognised symptom was.

STATISTICAL ANALYSIS

Descriptive statistics were reported as mean and standard deviation (SD) or median (range) where appropriate. Normality of outcome measures was established with the

Shapiro-Wilk test. Difference in proportion of participants in the information leaflet versus the hypoxia experience group who performed a self-initiated bailout was analysed with a Chi-square test. Differences between the information leaflet and hypoxia experience groups were analysed with independent *t*-tests and reported as mean difference with 95% confidence intervals (95% CI). For participants in the hypoxia experience group, consistency in all combined experienced symptoms was checked for each individual participant with Pearson correlation between the hypoxia experience and hypoxia testing exposure. All data were analysed with MATLAB version 2023b (Mathworks, Natick, MA, USA) and SPSS Statistics version 27.0 (IBM, Armonk, NY, USA), with α set at 5%.

Results

Forty participants completed the study, two participants were excluded from analysis due to technical malfunctions, leaving 38 participants for analysis. Participant characteristics are reported in Table 1. For the participants who underwent the unblinded hypoxia experience, the mean time interval between the hypoxia experience and the blinded hypoxia testing exposure was 60 days (range 28–107 days).

During the unblinded hypoxia experiences, many participants experienced very low SpO_2 levels before meeting the functional stopping criteria. The most hypoxic participant reached a SpO_2 of 38%, and the mean SpO_2 when reaching termination criteria was 60% (range 38 to 82%, Figure 3). On average the inspired fraction of oxygen at termination of the hypoxia experience was 5.2% (SD 0.8%). Hypoxia experiences lasted, on average, 7.3 minutes (SD 1 minute). All sessions were stopped because participants met the termination criteria; 6/20 by making mistakes, and 14/20 (70%) by no longer responding to the task. Unresponsiveness started at oxygen saturations as high as 85% and as low as 43%. Six participants correctly identified their number of mistakes, eight participants did not recall making any mistakes, three participants only recalled making one, and three participants recalled making more than five mistakes.

In the blinded hypoxia testing exposures, when compared to the hypoxia experiences, participants had higher SpO_2, inspired oxygen percentages, and shorter hypoxia durations at termination, likely because they were performing bailout procedures based on perceived symptoms. All participants achieved 'self-rescue' by operating the bailout valve on the rebreather mouthpiece. Six out of 18 participants (33%) in the information leaflet group, and 18 out of 20 divers (90%) in the unblinded hypoxia experience group, self-initiated bailout prior to the SpO_2 falling to 70% ($P < 0.001$, Figure 4). All other participants required (but appropriately responded to) the heads-up display prompt when SpO_2 fell

Table 1
Characteristics of the study participants. Note that the participants could identify as having more than one ethnicity

Parameter	Hypoxia experience *n* = 20	Information leaflet *n* = 18	Total *n* = 38
Age (mean years, range)	33 (18–53)	25 (21–33)	33.6 (18–53)
Female *n* (%)	8 (40)	6 (33)	14 (37)
Ethnicity *n* (%)			
European	9 (45)	12 (67)	21 (55)
Māori	2 (10)	1 (6)	3 (8)
Pacific peoples	1 (5)	0	1 (3)
Asian	2 (10)	0	2 (5)
Other	6 (30)	5 (28)	11 (29)
Education *n* (%)			
Secondary School	6 (30)	7 (39)	13 (34)
Bachelors	5 (25)	6 (33)	11 (29)
Masters	6 (30)	4 (22)	10 (26)
PhD or other doctorate	3 (15)	1 (6)	4 (11)
Diving history			
Years diving experience (median, range)	7 (< 1–19)	11 (< 1–34)	7 (< 1–34)
Number of dives (median, range)	86 (5–1,675)	225 (7–1,500)	104 (5–1,675)
Diving certification *n* (%)			
Open-circuit recreational	16 (80)	14 (78)	30 (79)
Open-circuit technical	2 (10)	2 (11)	4 (11)
Closed-circuit rebreather	2 (10)	2 (11)	4 (11)

Figure 3
Peripheral oxygen saturation (SpO_2) at bailout; yellow triangles denote participants in the hypoxia experience; blue circles represent participants who performed a bailout in the blinded testing exposure; purple squares represent participants who required a head-up display warning to perform the bailout

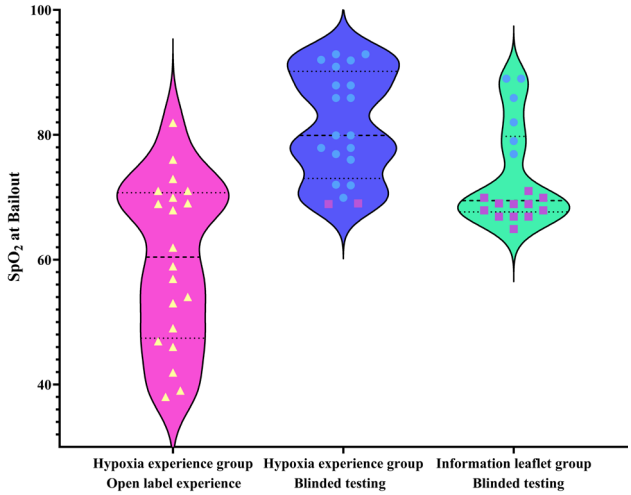
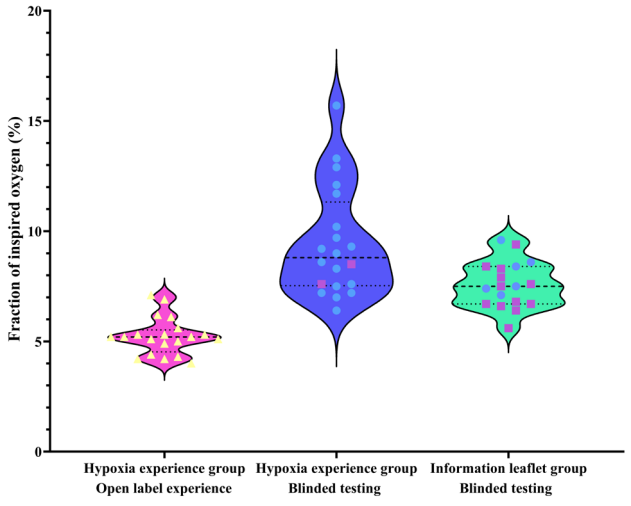
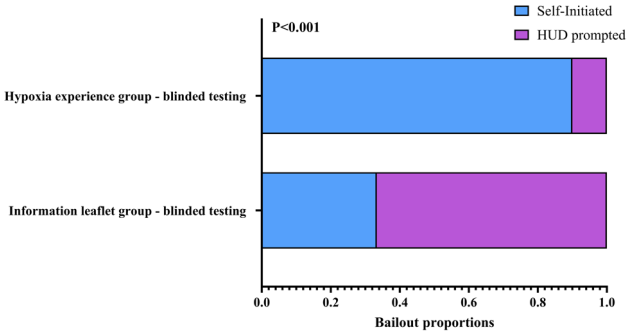


Figure 5
Fraction of inspired oxygen at bailout; yellow triangles denote participants in the hypoxia experience; blue circles represent participants who performed a bailout in the blinded testing exposure; purple squares represent participants who required a head-up display warning to perform the bailout



to 70%. When receiving a heads-up display prompt, it took participants, on average, 5.7 seconds to bail out (range 3.6 to 10.1 seconds). Time between the hypoxia experience and testing for the two HUD-prompted participants was 52 and 56 days. Divers in the information leaflet group had lower SpO_2 values (73.4% vs 81.4%, mean difference 8% (95% CI = 2.5 to 13.5%, $P = 0.005$, Figure 3) and lower inspired oxygen fractions (7.6% vs 9.4%, mean difference 1.8% (95% CI = 0.6 to 3.1%, $P = 0.005$, Figure 5) at bailout. The mean desaturation rate was 2.16%·min^{-1} (range 1.04–3.48) in the training and 2.49%·min^{-1} (range 1.14–3.38) in the

Figure 4
The proportion of self-initiated and heads-up display (HUD) prompted bailout in the hypoxia experience and information leaflet group during the blinded hypoxia testing exposure



information leaflet group ($P = 0.10$) during the blinded test exposure. For those who initiated self-rescue, there was no difference in SpO_2, inspired oxygen fraction, or time to bailout, regardless of receiving an information leaflet or an unblinded hypoxia experience.

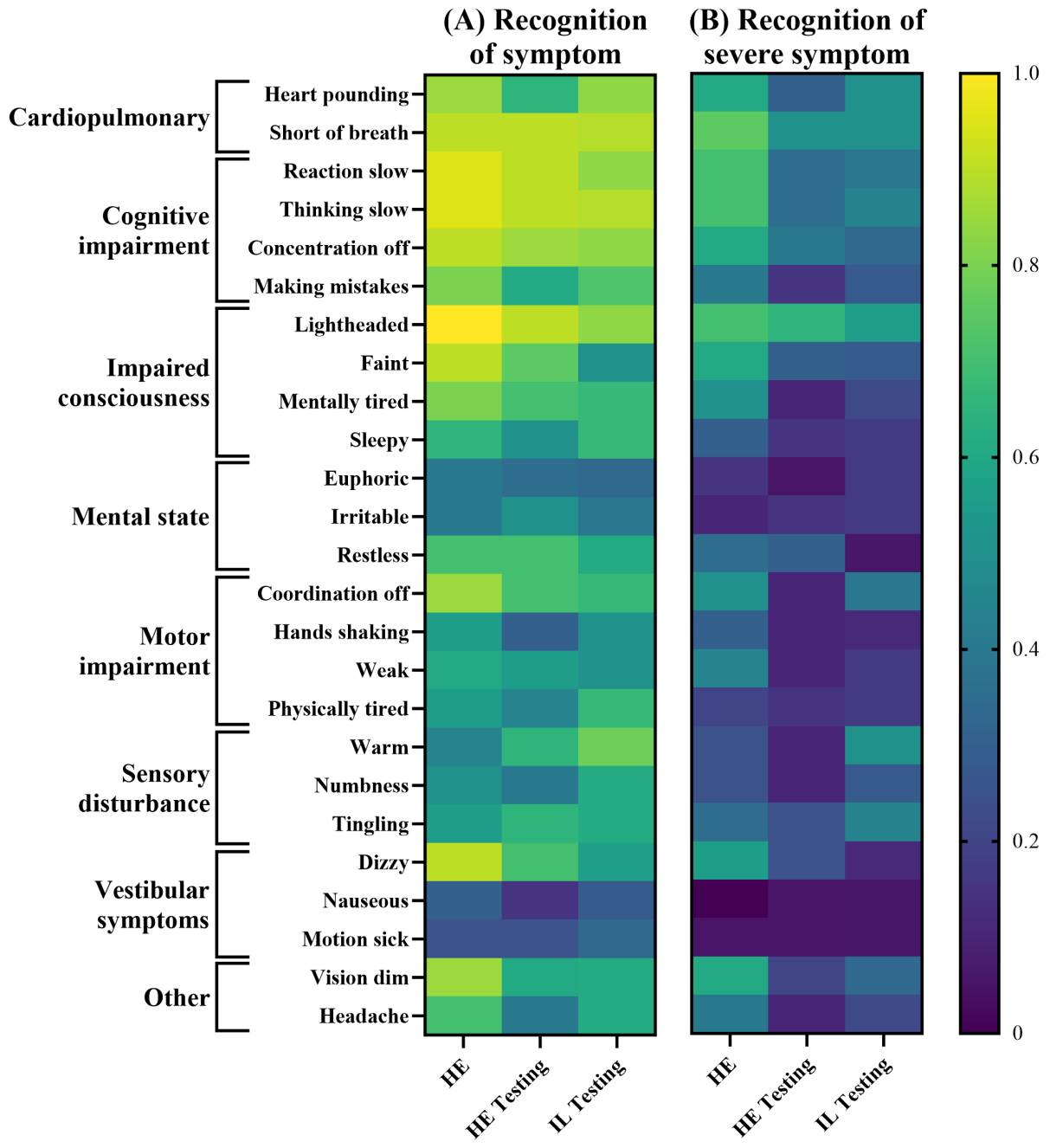
In both the unblinded hypoxia experience and the subsequent blinded hypoxia testing exposures, the two most frequently reported and most severely perceived symptoms were light-headedness and shortness of breath. During the unblinded hypoxia experiences, participants reported more numerous and intense symptoms compared to the hypoxia testing exposure accompanied by lower SpO_2 values. Reported symptoms were similar during the hypoxia testing exposure in both the information leaflet and hypoxia training groups (Figure 6). The first reported symptoms were shortness of breath (7/38, 18.4%), light-headedness (5/38, 13.2%), paraesthesia (5/38, 13.2%), feeling warm (4/38, 10.5%), impaired concentration (3/38, 7.9%), slow thinking (3/38, 7.9%), heart pounding (3/38, 7.9%), tunnel vision (3/38, 7.9%), increased blinking (2/38, 5.3%), slower reaction (1/38, 2.6%), feeling euphoric (1/38, 2.6%), and feeling tired (1/38, 2.6%). Of the 20 participants who underwent both an unblinded hypoxia experience and a subsequent hypoxia testing exposure, 14 (70%) had a correlated symptom signature (consistent symptoms between exposures), while six (30%) did not. Despite this, all six with an inconsistent hypoxia symptom profile performed a self-initiated bailout in the hypoxia testing exposure, while the participant requiring a heads-up display prompt had a consistent hypoxia symptom profile.

Discussion

We investigated the effect of a prior unblinded / open label hypoxia experience on the ability to self-rescue in a subsequent blinded hypoxia 'testing' exposure. Divers in the hypoxia experience group were approximately three times more likely to self-rescue (18/20, 90%) without prompting compared to those in the information leaflet group (6/18, 33%) before the SpO_2 fell below 70%. All participants

Figure 6

Self-reported symptom heatmap; heatmap A shows the recognition of a symptom (visual analogue scale score ≥ 5/100), and heatmap B shows the recognition of severe symptoms (visual analogue scale score ≥ 50/100). Yellow indicates all participants recognised this symptom (heatmap A) or recognised it as severe (heatmap B), while dark blue indicates no participant recognised this symptom (heatmap A) or recognised it as severe (heatmap B). HE – unblinded / open label hypoxia experience; HE Testing – hypoxia experience group during blinded hypoxia testing event; IL Testing – information leaflet group during blinded hypoxia testing event



in both groups were able to self-rescue if they received a heads-up display prompt. Hypoxia symptoms varied across participants; however, most participants who completed both the open label hypoxia experience and testing exposures exhibited a consistent within-individual symptom pattern. This consistency did not seem crucial to the participants' ability to self-rescue.

In 2022, Popa and colleagues conducted a study in which 20 divers underwent an unblinded hypoxia exposure using a similar approach to inducing hypoxia as reported here.[4] The experience was terminated when SpO_2 fell to 75%. Then, on the same day and often with very short intervening periods (as short as 10 minutes), participants underwent three blinded exposures, two normoxic and one hypoxic, in randomised order. During the hypoxia exposure, only

9/20 (45%) participants bailed out with no prompt. On this basis, the authors concluded that unblinded hypoxia training provided little benefit. Popa's findings differ from the present study in which 18/20 (90%) of participants who had a prior unblinded hypoxia experience self-rescued during the hypoxia testing exposure. Possible reasons for this difference include our allowing SpO_2 to fall to 70% before prompting participants to bailout which arguably provided a greater hypoxic stimulus to act, and the use of very mild exercise in the Popa study which may have caused a greater level of participant distraction and a faster decline in oxygen levels thus reducing useful cognitive function time to initiate self-rescue.

Interpretation of the Popa study requires cognisance of several other issues. First and most importantly, there was no comparator group that had not undergone hypoxia training experience. It is, therefore, possible that such a comparator group would have performed even more poorly than their universally trained cohort in relation to self-rescue. Second, it is also possible that participants had not fully cognitively recovered after the initial hypoxia exposure, even though SpO_2 had returned to normal. Full cognitive recovery, or disappearance of the 'hypoxia-hangover' takes at least 2–4 hours.[11] This may also explain the difference in responsiveness to a prompt to bailout between the Popa study (85%)[4] versus our study (100%).

Our laboratory-based finding of apparent training benefit after an open label hypoxia experience, while seemingly relevant to an aviation cockpit scenario (sedentary, cognitively distracted participants), cannot be extrapolated to the diving environment with strong confidence. Participants in our study self-initiated bailout at SpO_2 levels between 81.4 and 73.4%. These represent values near the top of the steep downward slope of the oxygen-haemoglobin dissociation curve and a further decline will result in a precipitous reduction in arterial oxygen content and a rapidly progressive risk of impairment and unconsciousness. Being immersed and exercising increases oxygen demand, resulting in faster depletion of oxygen levels in the body thus reducing useful cognitive function time to recognise a problem and self-rescue. Gas narcosis might further hamper the ability to perceive symptoms of hypoxia and to act on experienced symptoms. It is also notable that in the diving setting, hyperoxia and hypercapnia may also occur, and these may have some symptoms in common with hypoxia. Our study did not address a diver's ability to distinguish between these conditions. Nevertheless, the endpoint tested (bailout to a breathable gas) is a recommended intervention for all three conditions. If a diver incorrectly perceived symptoms of hypoxia produced by hypercapnia or hyperoxia and bailed out, it would still be the correct intervention in the vast majority of scenarios.

Hypoxia training research has mainly focused on consistency in the experienced symptoms of hypoxia between exposures.[4–8,12] All studies agree with our findings that light-headedness and shortness of breath, closely followed by cognitive impairment are the most frequently and severely reported symptoms.[4,6–8] This does not mean that all people, who become hypoxic, experience these symptoms. Many have tried to identify a 'hypoxia symptom signature'. Studies to date have analysed similarity of symptoms at group level,[6–8] or looked at within-individual consistency per one individual symptom.[12] We evaluated the individual symptom signature by correlating all symptoms of one individual between the open label experience and blinded testing exposures. The majority of people (70%) showed a consistent symptom signature. However, this consistent signature did not appear to result in better recognition of hypoxia in the blinded test exposure of our study.

There has been advocacy within the diving community for hypoxia training experiences in private or diver training facilities, particularly for rebreather divers. We strongly discourage the practice of intentionally inducing hypoxia outside of a purposive controlled environment with medically trained staff immediately available. Although none of our participants became unconscious, 70% became unresponsive to the card recognition stimulus. It is highly unlikely that these participants would have been able to rescue themselves. The level of preparation, organisation and attention required to prevent problems (and treat them if they occur) would not likely be replicated outside a highly supervised medical environment.

There are several limitations to this study which need to be acknowledged. First, the participants were healthy young divers. While this may be representative of military divers or aviators, recreational divers could be older and/or have undiagnosed (cardiovascular) health issues, which would negatively impact the safety of hypoxia experiences. The utility (and safety) of such experiences apparent from our highly selected study population cannot be extrapolated across the entire population of recreational divers. Second, although participants undertaking the blinded hypoxia testing exposures were told they could receive hypoxia or normoxia, all received a hypoxia exposure. This had the benefit of increasing the power of the study for the primary outcome, but limited our ability to identify 'false positives', i.e., participants bailing out during normoxic exposures. In the Popa study, 5/40 normoxic exposures were falsely identified as hypoxia.[4] This demonstrates that participants in such trials may be hypervigilant for hypoxia symptoms and illustrates the importance of an ecologically valid distracting task. In our case, we used a VR diving environment with an orca counting task as the distractor. Third, the desaturation rates were dependent on the individual oxygen consumption rate, and it would be extremely difficult to dynamically vary the fraction of inspired oxygen for each participants to ensure desaturation rates were identical in each individual. If desaturation rates were systematically different between the information leaflet and training experience groups during the test exposure, that could introduce a bias in relation to symptom perception, for example, earlier onset of hypoxia-

induced dyspnoea in a group becoming hypoxic more quickly. However, the desaturation rates were very similar between the two groups so we do not consider this a factor that may have influenced our results. Last, the time interval between the open-label hypoxia experience and the blinded hypoxia testing event was, on average, two months in this study. Aviators typically undergo hypoxia refresher training every three years.[8] It is unclear whether the improvement in recognition of hypoxia symptoms exhibited by the hypoxia experience group will persist after a much longer interval.

This study also had a number of strengths, including a head-to-head comparison of the effect of an unblinded hypoxia experience to an information leaflet on hypoxic symptom recognition, participant blinding, participant distraction, and the mimicking of real-life hypoxia onset in a failing closed-circuit rebreather. During this study, a suite of physiological data was recorded. We intend to present these additional data in a separate publication that focuses on the cardiovascular and respiratory physiological responses to severe hypoxia in humans.

These results support the use of hypoxia experiences to enhance symptom recognition in real-world emergencies as currently practised in aviation. It is interesting that such training became widespread in the absence of convincing evidence that it works. The existence of a 'hypoxic symptom signature' has been assumed to enhance recognition of a hypoxic event in real-world scenarios, but until recently, no studies designed to explicitly test the assumption have been conducted. Besides symptom recognition training, two technological methods for hypoxia detection in divers are proposed in the literature, including a wearable pulse oximeter,[13–15] and an oxygen monitor in the rebreather mouthpiece.[16] However, neither has been incorporated into commercial products because of signal reliability. It is known that due to the distance and blood flow, there is variability in pulse oximetry measurement depending on where the probe is placed, such as a 20 second delay at the finger and only a 5 second delay at the earlobe relative to the brain.[17,18] Furthermore, hypothermia can increase this delay at the extremities. Hence, pulse oximeter proximity to the brain should be considered in future to reduce delay and improve accuracy of results. Based on our study results, the detection limits need to be at least equivalent to a SpO_2 of 70% to be in time for an adequate response to bail-out. Ideally, the technology can recognise hypoxia before symptom onset.

Conclusions

In a controlled laboratory environment, divers who underwent an unblinded hypoxia experience were three times more likely to self-rescue in a subsequent blinded hypoxia testing exposure compared to those who only received a hypoxia symptom information leaflet. The majority of participants have a consistent individual symptom signature, which does not lead to earlier or better recognition of hypoxia. Being immersed, exercising and affected by gas narcosis could all negatively influence the ability to recognise and act on hypoxia symptoms. Future studies should examine if hypoxia training helps in symptom recognition after years, and whether such training decreases rebreather accidents.

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