THERMAL STATUS OF SATURATION DIVERS DURING OPERATIONAL DIVES IN THE NORTH SEA

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Abstract

The principal aim of the present study was to monitor the thermal status of a large population of divers conducting routine deep dives at different locations in the U.K. sector of the North Sea. A total of 30 divers, with an average (SD) of 19.3 (6.6) years of experience as saturation divers, participated in the study. Their physical characteristics were: age = 41.3 (5.6) yrs, height = 1.79 (0.07) m, weight = 83.9 (9.26) kg. The survey included 60 dives conducted at six locations (Scott Field, Norfra Pipeline, Hudson Field, Pierce Field, Forties Field and Bruce Field) from four Diver Support Vessels (Rockwater 1, Semi 2, Bar Protector and Discovery). The depth of the dives monitored ranged from 54 to 160 msw, and the duration of the dives from 31min to 7hrs 30 min. Prior to each dive, divers were requested to ingest a radio pill and strap a data logger to their abdomen. Upon returning to the chamber within the Diver Support Vessel following a dive, they provided subjective ratings of thermal perception (7 point scale) and thermal comfort (4 point scale) for the period just prior to, during, and immediately after the dive. Average (SD) gastrointestinal (core) temperature of saturation divers working at depths to 160 msw for up to 6 hours with water temperatures ranging from 4 to 6°C increased significantly ($p<0.001$) by 0.82 (0.65)°C from a pre-dive level of 37.4 (0.62)°C during the course of the dives. The subjective responses of divers indicated that they were thermally neutral (neither warm nor cold) and comfortable prior to dives, and on average reported being slightly warm ($p < 0.01$) during the dives. The current practice of providing thermal protection with hot water suits to saturation divers working in the North Sea is adequate for preventing core temperature cooling and eliminating the risk of hypothermia.

Introduction

Hypothermia has been implicated, either directly or indirectly, as a major cause of many diving fatalities (1-7). At the outset of offshore exploration, hypothermia was considered one of the major factors hindering diver performance (8), which could lead to loss of consciousness (1) and ultimately death (7, 9). Although, laboratory tests (10) have suggested that the heat provided by the hot water perfused suits is capable of offsetting the high heat loss, several reports have suggested that hypothermia remains prevalent among saturation divers in the North Sea (3-7). Keatinge *et al.* (6) measured the urine temperature of divers returning to the diving bell following routine dives and reported alarmingly low temperatures, indicative of mild-to-moderate hypothermia. In the absence of any visible signs of shivering or perception of cold by the divers, it was concluded that saturation divers are susceptible to 'symptomless hypothermia' or 'undetected hypothermia'. This has been attributed to the diver's altered temperature perception and consequent inability to detect core temperature cooling (11). This is critical because in such situations, the diver must adjust the water temperature to a level which minimises skin surface heat loss, and also the temperature of the breathing gas to minimise respiratory heat loss. Impaired temperature perception (12,13) has also been implicated in the occurrences of 'chilling' and 'scalding' reported among divers.

In view of the discrepancy between field observations and controlled laboratory studies, the present study was designed to survey the thermal status of saturation divers during operational dives in the North Sea. In contrast to previous studies, which were limited by the available technology at the time, a Diver Thermal Monitoring System was developed (14), which enabled continuous recording of deep body and surface temperatures during a complete work shift on the sea bed.

Methods

To ensure that the survey was representative of diving operations throughout the North Sea, field measurements were conducted on four DSVs operating in six locations in the UK sector of operations the North Sea (Table 1) in the period from November 1997 to May 1998.

Subjects

Thirty professional divers participated in the study ranging in age from 27 to 48 yr (mean $\pm$ SD = 41.3 $\pm$ 5.6). Subjects' physical characteristics are given in Table 2. The subjects received detailed information regarding the protocol and gave their written informed consent before participating in the study. The protocol was approved by a local Ethics Committee.

Protocol

All divers were saturated in a trimix environment in hyperbaric chambers aboard Diver Support Vessels (DSVs). They were in saturation for a maximum of 28 days and conducted dives on a rotational basis. Divers dived in groups of three, one diver acting as the 'bellman' and the remaining two conducting the open water dives. The maximum duration of the dives was 6 hours. A minimum of 12 divers were normally in saturation, providing a total of 4 dive teams. Diving was conducted on a continuous basis (24 hrs), thus each dive team completed one dive per day (24 hours).

During the dives, divers were provided with external heating. Hot water was pumped from the boiler on the DSV to the diving bell via an umbilical, and from there to a manifold on the divers' suits. High-pressure pumps delivered a steady flow of hot water at a maximum rate of 45 $l.min^{-1}$ to the bell. This flow of hot water was then partitioned between the two working divers in the water. Prior to being fed via an umbilical to the working divers, the water could also be circulated through a heat exchanger in the bell, providing heating for the bellman. The umbilical delivering hot water to the divers was connected to an external manifold on the divers neoprene wetsuit, and from there the hot water was distributed throughout the suit via a network of tubes. One tube ran the length of the back and the remaining tubes along each length of the limbs. The tubes had small perforations along their length, providing outlets for the hot water. At depths of 130 msw with water temperatures of 4 ºC, seawater heated to 55ºC onboard the DSV reached the divers at 38ºC. In the event that the heating was too excessive, the divers had the option of reducing the flow of hot water through the suit by manually adjusting a valve on a manifold, protruding from the suit. Temperature sensors provided Dive Control on the DSV

with water temperature at the boiler on board the vessel. No sensors were incorporated in the suits.

The diving procedures for all dives were similar, irrespective of the vessel and dive location. All dives were conducted in the UK sector of the North Sea, and the procedures and regulations of the Health and Safety Executive (UK) were strictly adhered to. Divers conducted a maximum of one dive in any 24-hour period. Maximum duration of any open water dive was 6 hours. In the event that they had to wait for equipment or engineering advice from the surface, they would return to the bell. In such situations, which were rare, their cumulative open water exposure was 6 hours over an 8-hour period. The length of the anticipated 'stand-by' period would determine whether the divers would either be returned to the DSV and wait for further instructions in the transfer lock of the hyperbaric facility, or wait in the bell at depth.

Instrumentation

Measurements of gastrointestinal and suit microclimate temperatures were made with a Temperature Monitoring System (Biomed d.o.o., Ljubjljana, Slovenia) comprising radio pills and data logger (14). At least one hour prior to their dive, calibrated radio pills and data loggers were transferred into the chamber through the medical lock. The logger was worn by the divers in a pouch strapped to the abdomen. Radio signals emitted by the temperature sensitive radio pill were received by the logger, and stored in memory for subsequent transfer to a PC on board the DSV. Thermistors embedded in the sides of the logger provided information regarding the temperature of the suit microenvironment.

Divers provided subjective ratings of thermal perception (7-point scale: 1-cold, 2-cool, 3-slightly cool, 4 neutral, 5-slightly warm, 6-warm, 7- hot) and thermal comfort (4-point scale: 1-comfortable, 2-slightly uncomfortable, 3-uncomfortable, 4-very uncomfortable) before and during the dive.

Statistical analyses

Gastrointestinal temperatures prior to and at the end of each dive were compared with a Paired t-test. Divers' subjective ratings of temperature perception and thermal comfort before and during the dives were compared with a Wilcoxon Signed Rank Test.

Results

Of the 60 dives monitored, 31 were conducted at depths greater than 100msw and 29 at depths shallower than 100msw. During six of the dives monitored, the diver being monitored was the bellman (of these, 2 dives >100 msw and 4 dives <100 msw), whereas the remaining data corresponds to divers working in the open water (of these, 29 dives >100 msw and 25 dives < 100 msw). All dives monitored were asymptomatic.

Suit microenvironment temperature (Tμ)

In all the dives monitored the hot water suits functioned properly, allowing the divers to regulate the temperature of the suit microenvironment. As shown in Fig.1 (top), suit microenvironment temperatures (Tμ) increased from 32.2 $\pm$ 1.4 °C at the onset of the dives to 34.7 $\pm$ 1.7°C within one hour of the dive ($p < 0.001$).

Bellmen were not connected to the hot water supply, and thus their suit microenvironment temperatures were maintained at lower levels, as shown in Fig. 1 (bottom). Their Tμ was on average between 32 and 34°C, with some bellmen maintaining suit temperature as high as 37.3 °C.

Gastrointestinal temperature (Tpill)

Divers' core temperature, as measured by the radio pill, increased significantly ($p < 0.0001$) from average pre-dive levels of 37.4 $\pm$ 0.6 °C by 0.8 $\pm$ 0.7 °C during the 6 hour dives (Fig. 2, top). In contrast, there was no significant change in the core temperature of the bellmen (Fig. 2, bottom) during the 6 hour dives.

Thermal comfort

Divers' (N=30) subjective ratings of Temperature Perception and Thermal Comfort indicated that they were thermally neutral (median rating of 4 on 7-point Temperature Perception scale) and comfortable (median rating of 1 on 4-point Thermal Comfort scale) prior to the dive, but became slightly warm (median rating of 5 on Temperature perception scale; $p < 0.01$) and slightly uncomfortable (median rating of 2 on Thermal Comfort scale; $p < 0.01$) during the dive. In contrast, the bellmen (N=4) reported being thermally neutral (median rating of 4) and comfortable (median rating of 1) prior to and during the dives.

Discussion

The principal finding of the present study is that saturation divers working at depths to 160 msw for up to 6 hours, in water with average temperatures of 4°C, do not experience any significant changes in body temperature. The hot water perfused suits currently being used by deep sea divers in the North Sea safeguard against hypothermia. There was no evidence of any impaired thermal perception in the present study. No scalding or chilling was experienced by the divers during the use of the hot water perfused suits and divers perceived the increases in Tsk and Tc as reflected in their subjective ratings, suggesting that thermal perception and thus behavioural thermoregulation was not impaired.

The absence of shivering in previous studies of divers with urine temperatures at hypothermic levels may be attributed to either an effect of the hyperbaric heliox (helium-oxygen) or trimix (helium-oxygen-nitrogen) on the shivering response, or to an underestimation of core temperature on the basis of urine temperature. With regards to the former, inert gas narcosis (16) has been demonstrated to suppress shivering during compressed air diving. However, it is unlikely that such an effect on heat production can be attributed to the development of hypothermia in dives, where divers breathe heliox or trimix gas mixtures, as helium does not exert a narcotic influence at depths of 200 msw.

A more likely explanation for the observed near-hypothermia of the divers returning to the diving bell is the manner in which core temperature was assessed. Påsche et al. (10) observed that urine temperature of divers completing experimental dives in cold water at 51 ATA for up to 3 hours was 0.3 to 0.8 °C lower than rectal temperature and concluded that urine temperature underestimates core temperature.

Much concern regarding divers' thermal balance was raised by the study of Padbury et al. (11) who reported considerable core temperature cooling in a series of 25 laboratory dives. In their study 14 divers exhibited a decrease (-0.49 $\pm$ 0.38 °C), six an increase (+0.18 $\pm$ 0.12 °C) and four no change in rectal temperature (Tre). The average change in Tre in their group of divers was from 37.55 $\pm$ 0.53 °C (pre-dive) to 37.29 $\pm$ 0.61°C (post-dive). Interestingly, four of the divers started the dive with rectal temperatures, which would be considered reflecting mild hyperthermia (range: 38 to 39.5 °C). Thus, in 10 divers the observed decrements in Tre, for example from 39.5 to 39.0 °C (difference: -0.5 °C) or from 38.0 to 37.3 °C (difference: -0.7 °C), although large in magnitude, do not reflect a core cooling from euthermic to hypothermic levels, but rather from hyperthermic to euthermic levels.

Since the publication of earlier reports regarding the occurrence of hypothermia among North Sea divers, diving procedures and practices have changed.

This may also have contributed to an improvement of the divers' ability to maintain thermal balance, as evidenced in the present study.

Conclusion

During routine deep diving operations in the North Sea, the current diving procedures and the provision of hot water perfused suits is adequate in preventing deleterious decrements in deep body temperature. The increments in skin and core temperature observed during 6-hour dives at depths ranging from 54 to 160 msw were perceived by the divers, suggesting that there thermal sensation is not impaired under such conditions and that they can rely on proper behavioural modifications (responses) as the first line of defence in maintaining thermal balance.

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Table 1. Characteristics of dives monitored.

Location	Diver Support Vessel	No. of dives monitored	Maximum depth (msw)	Maximm duration (hrs:min)
Scott Field	Rockwater 1	4	131	6:40
Bruce Field	Rockwater 1	11	122	6:00
Hudson Field	Rockwater 1	3	160	5:20
Norfra Pipeline	Bar Protector	3	58	3:55
Pierce Field	Semi 2	26	82	7:30
Forties Field	Discovery	13	124	5:59

Table 2. Subjects' physical characteristics.

	Age (yr.)	Height (m)	Weight (kg)	S.A. (m^2)	Body fat[15] (%)	Experience (yr.)
Mean	41.3	1.79	83.9	1.95	24.0	19.3
$\pm$ SD	5.6	0.07	9.26	0.4	3.75	6.6
Range: Min	27	1.65	70.0	1.78	15.1	4
Max	48	1.93	97.0	2.24	31.0	33

Figure legends

Figure 1. Temperature within the microclimate of wet suits of divers (top) and bellmen (bottom) during the dives.

Figure 2. Change in gastrointestinal temperature as recorded by the temperature-sensitive radio pill, relative to pre-dive levels of divers (top) and bellmen (bottom) working in open water at depths ranging from 52 to 162 msw for up to 6 hours.

Figure 1

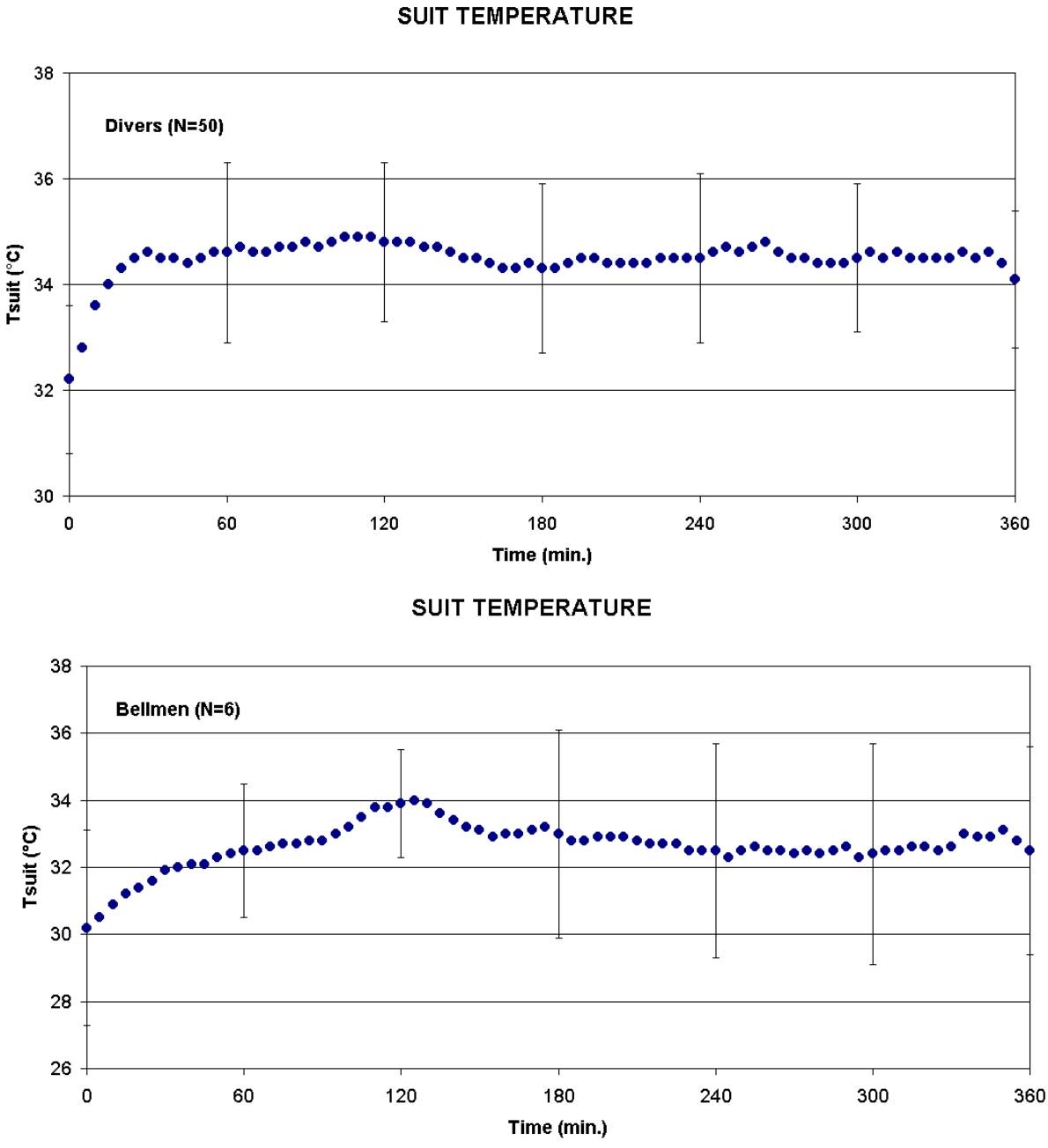
SUIT TEMPERATURE
Divers (N=50)
Tsuit (°C)
38
36
34
32
30
0
60
120
180
240
300
360
Time (min.)
SUIT TEMPERATURE
Bellmen (N=6)
Tsuit (°C)
38
36
34
32
30
28
26
0
60
120
180
240
300
360
Time (min.)

Figure 2