SOME OBSERVATIONS ON HYPOTHERMIA

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Hypothermia is an ever-present hazard to divers, especially in winter. As most divers know little or nothing of its effects it is fortunate that most people dive with a single 72 cu ft cylinder and lack of air makes them leave the water before they are too chilled.

Mr A, a shipwright in his 30's, had learnt to dive so that he could clean yachts bottoms without slipping the boats. His other duties meant working underwater most of Saturday and Sunday. He had a partner who helped him in this task, but the partner developed trouble with his ears and stopped diving. So Mr A spent even more time underwater. As the summer ended and winter closed in he noticed increased frequency of micturition and urgency. This inability to hold his water was new and was the reason for him consulting a doctor. As the story unfolded he mentioned that once he could not remember whether he had scrubbed one side of a yacht's bottom when he got out of the water. When he checked he found he had indeed scrubbed the boat's bottom on both sides, but the last thing that he remembered was going round the rudder. On another occasion he had watched his arm scrubbing backwards and forwards while he noted that he could not feel his arm moving, and he was not consciously moving it. His main interest at that moment was a sensation of terrible cold and a desire to get out of the water, which he soon did. One day his partner pulled him from the water when he saw him "just sitting there" instead of working. Mr A thought these episodes odd, but not odd enough to seek advice. However he had bought a longer pair of wet suit trousers to try to keep out the cold.

His work involved 3 hours or more in the water at a stretch. He emerged briefly when one bottom was scrubbed, long enough to get to the next yacht. Each took some 1.5 hours to scrub clean. He was seldom more than 7 feet from the surface. He sat rather than swam and performed a constant to and fro movement which meant that there was a constant flow of water into the jacket of his wet suit. After spending the morning in the water he would have an hour's break for lunch and then re-enter the water.

This man had obviously suffered from hypothermia without realising what was happening as he was working in water of about 9.5 to 12.5°C (which is the range of Port Phillip Bay water at St Kilda in winter according to the Bureau of Meteorology).

When a diver enters cold water there is an immediate decrease in blood flow to the skin. This cold induced reaction is partly mediated by sympathetic hollow nerves and partly by the direct effect of cold on the blood vessels. The next result is a fairly rapid reduction in heat loss from the limbs.

As a result of this peripheral vasoconstriction there is a short lived, about 5 minutes, paradoxical rise of deep body temperature as centrally produced heat from the liver, heart, kidneys and intestines is not being distributed normally to the limbs and has nowhere to go. But this happy state of affairs does not last as heat loss through the chest and abdominal wall is mainly by conduction and is little influenced by skin vaso-constriction.

Figure 1 (redrawn after Beckman and Reeves) shows how the rectal temperature of an asthenic (thin?) subject dropped over 2 hours sitting in water at (74°F), which is temperature was accompanied by a marked increase in metabolic heat, which however was not sufficient to stop the drop in temperature although the rate of drop declined. However by the end two hours this man's heat output was dropping and he had to be removed from the water. Mr A was in water 10-14°C colder.

The subject of Beckman and Reeves experiment was unclothed while Mr A wore a 3/16th wet suit. Wet suits are quite efficient insulators when subject is close to the surface and motionless. They depend for their efficiency on the closed aircells in the neoprene (which are compressed at depth and so become less efficient) acting as insulation, and the presence of a thin layer of still water, warmed to skin temperature, between the skin and the wet suit. Movement exchanges this warmed water for cold and accelerates cooling.

Figure 2 (redrawn after Craig 1966) shows that there are three rates of heat loss with an unclad subject entering the water. The first steep slope, a high rate of loss, is the heat loss from the limbs and skin as vascular regulatory mechanisms come into play and the limbs and skin cool to near water temperature. The second slope, a loss rate about 1/5th of the initial, is that experienced when skin temperatures have dropped to approximately that of the surrounding water and limb vasoconstriction is leading to very low blood flows and so less loss of heat. Forearm flows as low as 0.5ml 100^{-1} min^{-1} at 13°C have been recorded while the blood flow was 17.6ml 100^{-1} min^{-1} in water at 45°C (Barcroft and Edholm, quoted by Keatinge). This low flow is cooled effectively as the main limb veins lie close to the main arterial supply and heat exchange occurs between the two. So little heat is lost from the limbs while just sitting still. Movement increases muscle requirements for oxygen and so increases blood flow, leading to an increased loss of heat. The third slope is about 1/10th of the rate of loss of the second and is the result of increased heat production. But the body is still losing heat. Little work has been done on the rate of heat loss in men wearing wetsuits, but Dr Craig tells me that the effect of a wet suit is to abolish or reduce the large initial heat loss while not altering the other two rates of loss. This refers to men sitting in a stirred water bath.

Figure 3 (redrawn after Pugh) shows the effect of exercise, in this case swimming, on the rectal temperature of a thin subject in water at 16°C. The upper line is sitting while the lower one is swimming. In both cases the man was too cold to continue after 30 minutes, although his core temperature has dropped much less while sitting than when swimming. The hollow lines show how the core temperature continued to drop after he had been taken out of the water. This continuation of cooling after active cooling has stopped is known as the "after drop". In this case the swimming exposure had to be terminated as he could no longer keep himself afloat.

Figure 4 (redrawn after Pugh) shows that even in water as warm as 25°C (77°F) a thin subject loses heat. While at 16°C (61°F) he was unable to continue swimming after 30 minutes and in water at 20.5°C (69°F) he was rendered immobile by hypothermia in 45 minutes. This man was thin, he had an average of 5mm of fat on his body. However a fat man (fat 30 mm thick on his abdomen and 20 mm on his back) had different responses. This well insulated man maintained his core temperature better when swimming than when sitting. Heat loss is all a question of insulation and heat generation. If the heat can be retained inside the insulation not much can get away.

The dangers of hypothermia for the diver are mainly those of failing mental faculties, slowing of thought and reactions and inappropriate responses. These occur before loss of muscle power, which of itself can lead to drowning.

Divers suffer from acute hypothermia and the treatment is acute rewarming. When the patient has been hypothermic for many hours the effects of cold diuresis, which reduces blood volume, and of a thoroughly cold heart which is beating slowly and inefficiently, combined with rapid rewarming with its consequent vasodilatation are often fatal. These patients should be insulated so that they lose no more heat and then left to rewarm themselves with their own heat production.

Most of the knowledge we have about hypothermia is from hypothermic anaesthesia where the aim is to cool the body, and brain, so that the cerebral circulation can safely be interrupted. These low temperatures with their risks of cardiac arrythmias are not likely to be attained by diver unless he is left unconscious in the water.

Although there are individual variations most people are incapacitated by cold at a rectal temperature of 34.5°C and many are too cold to tolerate continued immersion even above rectal temperatures of 37°C. At these temperatures the heart rate has not been slowed significantly by cold.

The dangers of hypothermia are greater if the diver dives again before he has regained all his lost heat. Figure 3 shows that even 1.25 hours after leaving the water the swimmer in 20.5°C water had not regained his starting rectal temperature. Had he then re-entered the water his endurance would have been much reduced as he had less total body heat to supply losses to the water. It is of interest that the exposure with the higher (20.5 C) temperature in Figure 4 when the man was incapacitated at a rectal temperature of 34.5 C, the same temperature as he was incapacitated in water at 16°C, he took longer to restore his total body heat than when exposed to colder water. Cold vasodilatation probably played its part in the rapid cooling in the colder water. In this condition the blood vessels suddenly dilate and the limb is flushed with blood for a minute or two before vasoconstriction recurs. This effectively cools the blood and the heart and the core of the body. In slightly warmer water, not cold enough for this to happen, cold seeps into the body from the surface and it took longer for the core temperature to drop, but there is more very cold tissue to warm after the cold exposure is completed.

Mr A was advised to wear a wet suit hood, gloves and boots, and a second wet suit top (so increasing the available insulation and cutting down portals of entry for fresh, cold water). He was advised to have a hot bath or shower and a hot drink during his lunch break and most importantly have a longer lunch break and never to get into the water unless he felt warm.

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Further reading:

Beckman EL and Reeves E. Physiological implications as to survival during water immersion at 75°F. *Aerospace Medicine*. 1966; November: 1136-1142.

Craig AB and Dvorak M. Thermal regulation during water immersion. *Journal of Applied Physiology*. 1966; 21: 1577-1585.

Craig, AB and Dvorak M. Thermal regulation of man exercising during water immersion. *Journal of Applied Physiology*. 1968; 25: 28-35.

Craig AB. Heat exchange between man and the water environment. In *Underwater Physiology.* Ed. Lambertsen CJ. New York and London. Academic Press. 1971: 425-433.

Golden FSt C and Rivers FJ. The immersion incident. *Anaesthesia*. 1975; 30: 364-373.

Hayward JS, Echerson JD and Collis ML. Effect of behavioural variables on cooling rate of man in cold water. *Journal of Applied Physiology*. 1975; 38: 1073-1077.

Keatinge WR. *Survival in cold water*. Oxford: Blackwell Scientific Publications, 1969.

Pugh LGCE. Temperature regulation in swimmers. In *Physiology of Breathhold diving*. Ed. H Rahn. National Academy of Science - National Research Council Publication 1341. 1965: 325-348.

Vaughan WS. Diver temperature and performance changes during long-duration, cold water exposure. *Undersea Biomedical Research*. 1975; 2: 75-88.

Webb P. Thermal problems in diving. *Undersea Medical Society report* No. WS. 12-1-74. 1974.

Webb P. Cold exposure. In *Physiology and Medicine of diving and compressed air work*. Ed Bennett FB and Elliott DH. London; Bailliers Tindall 1975: p 285-306.

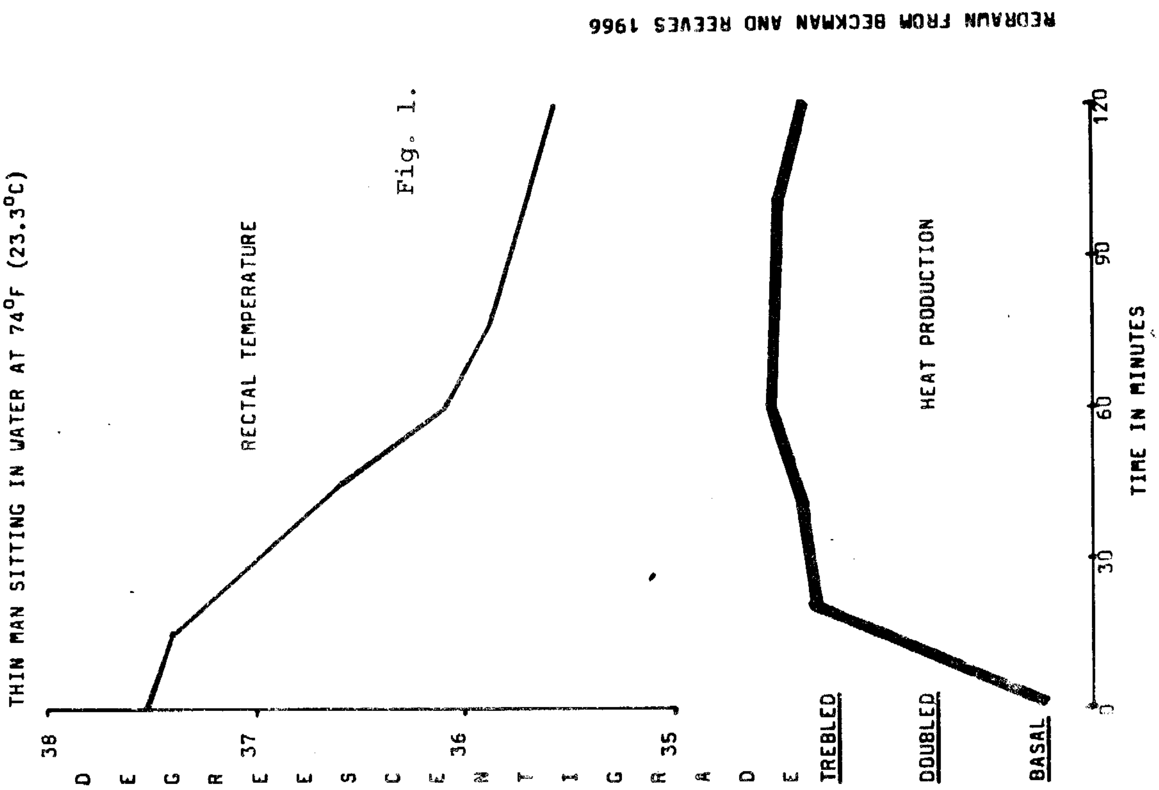

Fig. 1.

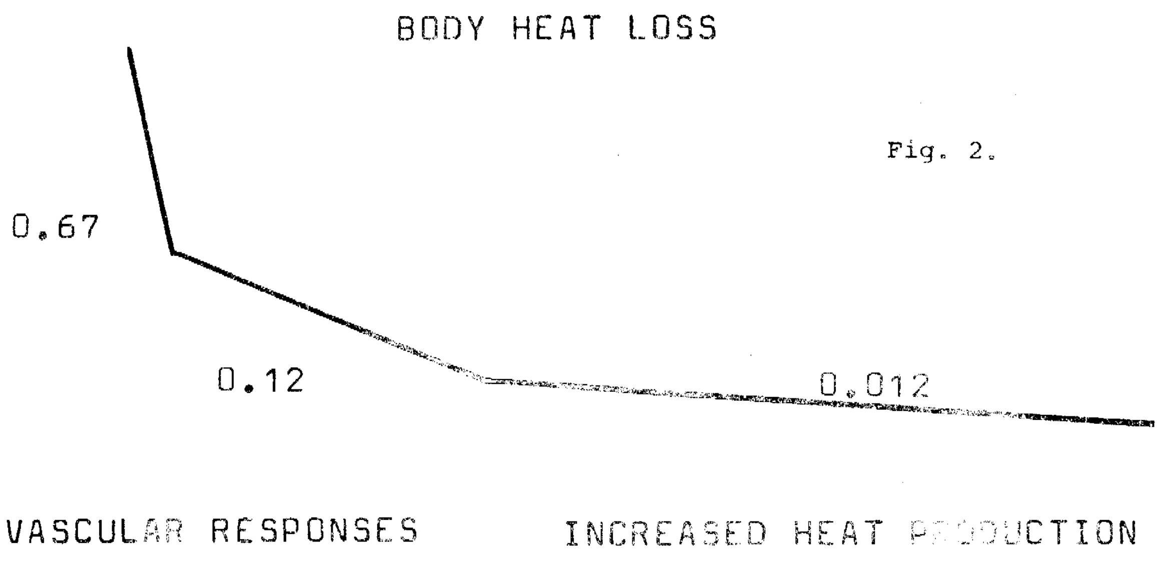

Fig. 2.

FIGURES IN C/HR PER °C TEMPERATURE DIFFERENTIAL
BETWEEN BODY CORE AND WATER
(AFTER CRAIG 1966)

RECTAL TEMPERATURES OF A THIN MAN SWIMMING IN WATER

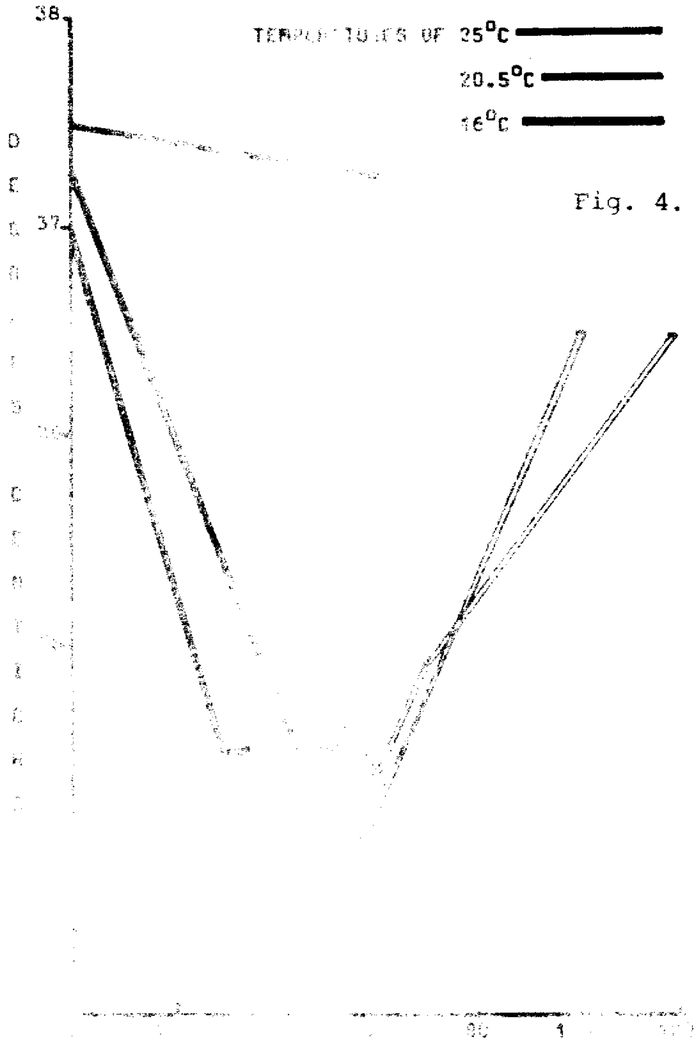

Fig. 4.

RECTAL TEMPERATURES OF A THIN MAN IN WATER

AT 16° C

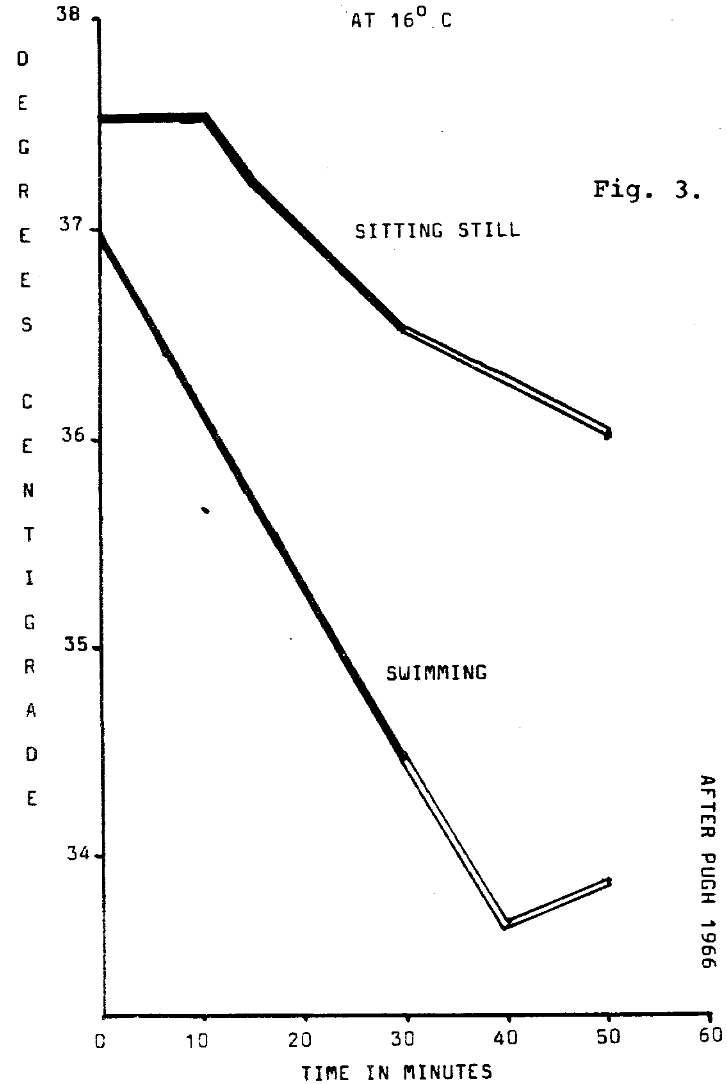

Fig. 3.