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Abstract
From a dissertation to the Society on 18th October, 1963.

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SURVIVAL IN COLD WATER

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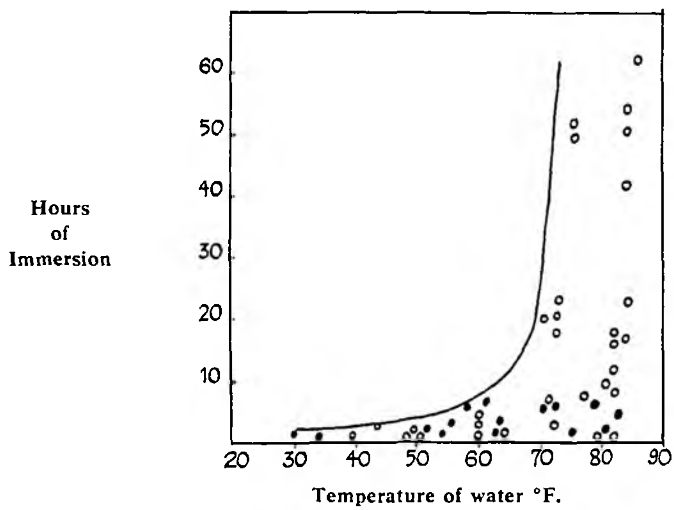
Each of these records is represented by a point on Fig. 1. The continuous line is drawn above all of the points, and it indicates very roughly the point of demarkation between survival on one side and death on the other. Each point below the line represents an individual who has survived. This measure, of course, cannot be expected to apply in all cases. It is only a rough guide. Many other factors may contribute to shortened survival such as drowning in heavy seas, fainting, exhaustion and injuries. Molnar points out that the line represents a hyperbola. This indicates perhaps that the product of the deficiency in water temperature and the survival time equals a constant. That is to say death occurs once a *critical body temperature* has been reached.

Alexander reports on cold immersion trials carried out in Dachau concentration camp.

Fig. 1



These trials are of limited value because the height and weight is given in only five of the subjects used. The subjects in question were clothed in aviators garb; that includes head-gear and a rubber or kapok life-jacket. Fig. 2 shows the results of thirty-six experiments. The white dots represent subjects who survived the immersion, whereas the black dots represent twelve subjects who perished. Individual variation is marked. The chart includes the results of another experiment carried out by Spealman. The subjects were immersed in water as low as 50°F, the lowest temperature that he considered safe. From the results he calculated a "safety limit" which is represented by the lightly dotted line. The heavily dotted line is a rough average of the Dachau results. The continuous line is taken from the previous chart, and evidently represents the outside limit of tolerance. Few will survive longer than it indicates. One hour in water at 50°F can be expected to kill 50 per cent. of people. This is a generalisation, but provides a figure that is easily remembered. Conversely it could be said that few more survive a drop in rectal temperature below 78.5°F.

Fig. 3 is based on the fall in rectal temperature over the first hour of immersion at various water temperatures. It is based upon Spealman's figures, with the Dachau figure marked in the circle at the top of the graph. In water at 75°F the fall in rectal temperature is 2°F per hour, at 55°F it is 5°F per hour, and at 45°F the fall is about 12°F per hour. For succeeding hours of immersion this cooling rate can be produced in a linear fashion until the lethal temperature is reached. There seems to be a number of people who survive rather longer than these measurements suggest. In such cases the cooling, subsequent to the first hour, probably occurs exponentially, and not in a linear fashion. Perhaps the same subjects can withstand a greater fall in rectal temperature than is considered usual. This, however, is only surmise.

If, on the other hand, the temperature of the water is reasonably warm, that is to say above 60-68°F, the rectal temperature falls to a new level within the first hour, achieving a new equilibrium. Heat production is stepped up by three to six times the usual rate in response to the cold, and soon keeps pace with the heat-loss, albeit at a lower internal body temperature. This explains why there is a such a very sharp increase in the number of people that survive long hours of immersion once the temperature gets above 60-68°F (Fig. 1). In colder water no equilibrium is reached.

In water the body cools at just twice the speed that it would in air at the same temperature, although water conducts heat twenty-five times faster than air. The limiting factor is the conductivity of the body, which cannot be reduced below a certain level once vaso-constriction is complete, then the internal gradient of temperature will depend upon such factors as body-build and the clothing worn. The greater heat-loss in water is also contributed to by the following factors. First of all there is a greater effective surface area presented by the body to the water; this is because one leg cannot exchange heat with the inside of the other, nor the arm with the lateral chest-wall. Secondly the layer of water immediately surrounding the body has a greater specific heat than a similar layer of air. And thirdly the water-layer is more readily disrupted. These factors cause the external surface temperature of the body to be lower than it would have been in air at the same temperature. The internal heat gradient is therefore steeper, and heat-loss will therefore be quicker. In water at 60°F and below, the internal body temperature continues to fall. When it is below 90°F you reach the paradoxical situation of heat production being impaired for want of heat energy. At 80 to 88°F it is barely at the B.M.R.; cardiac and respiratory irregularities occur, which if allowed to continue, lead to death.

There are certain factors which influence the maintenance of body temperature in the water, some of which were investigated by Keatinge in 1959. The question of work is quite important, because up to then it was not known whether the survivor should be encouraged to swim around vigorously in the water or not. The results produced were quite interesting. They found that in water at 5°C and 15°C, work tended to quicken the fall in rectal temperature. This was so whether the men were clothed or not, whether they worked as hard as possible or only a little, and whether the water was vigorously stirred or not. In water that was above 25°C the opposite was found. Work reduced the fall in body temperature and was presumably beneficial. But since water at this temperature is far less dangerous anyway it does not matter so much. The musculature was in better condition after work, and

Fig. 2

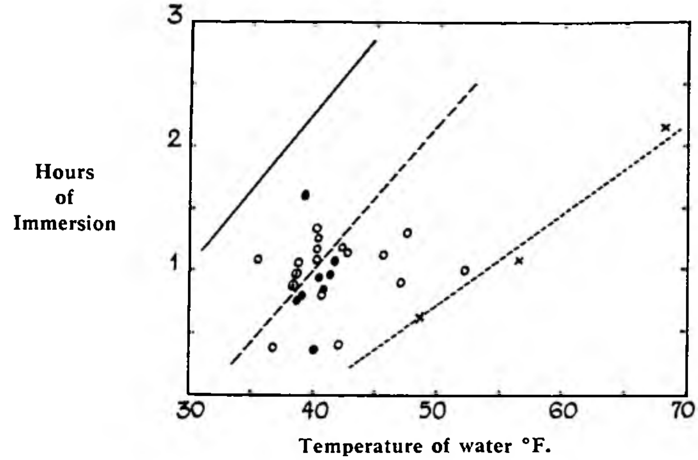
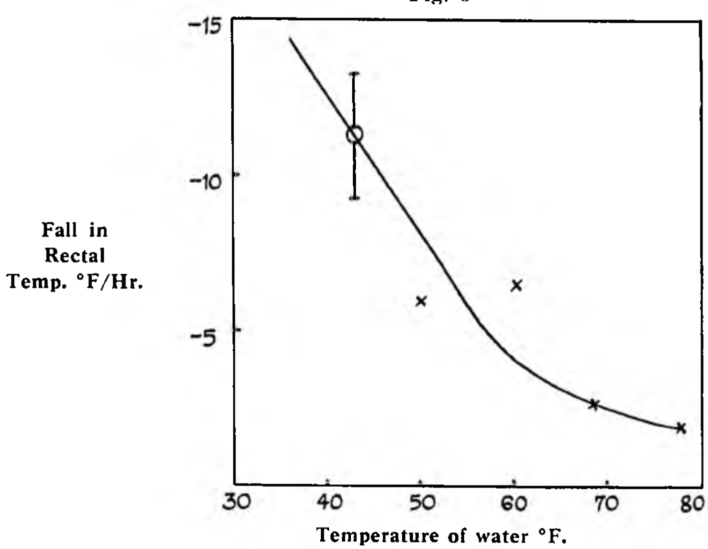


Fig. 3



this meant that they could climb on to a raft more easily.

As regards the effect of clothing, the deep body temperature did not fall as rapidly in the clothed subject as in the unclothed, especially when they did not move. This was also true of the superficial temperature. The standard clothing was not waterproof.

Three other items were investigated; meals, previous exposure and the drug hyoscine. If a heavy meal had been taken three-quarters of an hour beforehand, then a greater risk of developing cardiac irregularities occurred, especially in very cold water. Previous exposure made little difference. It appeared that whether a man was warm or cool, had taken exercise or remained still before being immersed, the effect upon the falling rectal temperature was only very slight. Those who were hot when entering the water cooled more rapidly, but remained slightly warmer than the others throughout the experiment. Hyoscine produced quite definite hyperventilation in some cases, explaining perhaps the muscle-cramps that were experienced by one subject. The same man did not have cramp at any other time. Since hyoscine is the standard remedy for sea-sickness, this may present a hazard, but not a major one.

The question of hyperventilation brings us on to another problem. That is the changes in alveolar p.CO_2 which are produced in a subject immersed in cold water. Suggestions have been made that the alveolar p.CO_2 level became dangerously high in a man who worked hard in cold water.

This is quite obviously untrue. On the first occasion when men sat unclothed in the water at 15°C their end-tidal p.CO_2 *decreased* by an average of 1.8 mm.Hg. in the first four minutes. At 5°C the decrease was 4.5 mm.Hg. These are end-tidal measurements, and represent an even larger decrease in alveolar p.CO_2, perhaps to the extent of endangering the normal working of the ventricles. However, this situation had approximately righted itself by the end of a twenty-minute period. Extra systoles were recorded on a number of occasions. In one case they were multiple. This happened in water at 15° and below. It is tentatively suggested that ventricular fibrillation is one cause of sudden death on immersion into cold water.

By far the most spectacular finding was the cooling-rate of the body in relation to the thickness of the subject's sub-cutaneous fat. Fig. 4 shows the fall in rectal temperature in degrees Centigrade during a thirty-minute immersion in water at 15°C. The abscissa is the reciprocal of the thickness of a fold of skin. A number of measurements, using calipers, are made from specified sites on the body, and the mean of these is the value used. On the one hand a man whose skin-fold thickness was 10 mm. only loses 0.5°C in half an hour, whilst on the other a man whose skin-fold thickness is only 5 mm. loses four times as much—that is 2°C in half an hour.

The problem of immersion in cold water is part of the larger problem of survival. Having realised the full extent of the threat, it has been investigated and certain facts are emerging. For example, the rapid loss of heat from the body is made worse by movement. The importance of clothing and fat in protection against the cold, has led the Navy to experiment with special rubber "Survival Suits", which can be put on in a matter of 20-30 seconds before jumping into the water. They are worn over the clothing, thus making sure of a thick layer of insulation. The design has not been perfected yet, but tests carried out with a number of these suits have given very encouraging results. Meanwhile the danger remains very real. It is rather horrifying to think what would have happened in the recent sea-disaster, had the sea temperature been the same as that surrounding the iceberg which sank the "Titanic".

Medical Research Council: Reports prepared for the Royal Naval Personnel Research Committee—Survival at Sea Sub-committee.

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Fig. 4