

Chapter 7

SURVIVAL TIME IN COLD WATER

Generally, a search usually isn't commenced until a boat is overdue for more than 24 hours. Fortunately for the passengers and crew of the fishing boat "COUGAR", which sunk 13°C (56°F) water, 35 miles off the coast of Oregon in September 1998, the absence of a normally punctilious individual, Capt Liddell, from a meeting raised the alarm and triggered the search. He, along with five others, was rescued after 18 hours in the water. Sadly four died before rescue. Had the normal search practice been operated, all would have died.

Knowledge of the estimated survival time of an individual immersed in cold water is seminal in the formulation and execution of search and rescue policies, as well as being important in the selection and purchase of protective survival equipment. For example, in the above incident the availability of liferafts or immersion suits could have prevented loss of life.

The potential usefulness of accurate estimations of survival time for such predictive and prescriptive purposes has resulted in a good deal of attention being concentrated on the area over the last fifty years. However, in spite of this, and in some cases because of it, the prediction of survival time in cold water remains more of an art than a science. Confusion appears to abound and an accurate, robust and comprehensive set of predictions remains elusive. As recently as 1996, in a UK Health and Safety Executive report on the subject, it was concluded: *"There is still a need to define a realistic estimate of probable survival times for people immersed in the (North) Sea"* (Robertson & Simpson, 1995). In the following section we examine why this is the case.

ESTIMATIONS OF SURVIVAL TIME

The first attempt to quantify the precise relationship between water temperature and survival time was made by George Molnar in 1946. He performed a retrospective analysis of an unspecified number of "selected" US Navy records of ship sinkings and aircraft ditchings during WWII. Using data only from those incidents for which precise details of seawater temperature and time of immersion were available, he compiled a graph of survival time against water temperature (Fig. 7.1). This displays a curve above the highest recorded survival times that, *"represents a limit of tolerance which probably few men can exceed and many cannot even approach"*.

Figure 7.1. *The "Molnar (survival) Curve".*

(Molnar, GW. 1946)

Molnar's analysis was limited to only five data points for water temperature at or below 7°C (42.5°F). For temperatures below 10°C (50°F), he employed survival times extrapolated from the infamous immersion experiments undertaken at the Nazi's Dachau concentration camp. Molnar's resulting survival curve is therefore relatively crude, in so far as it provides guidance to the nearest couple of hours. However, it did identify, for the first time, that survival time in water below 15°C (59°F) was relatively short, and suggested that above this temperature it increased reasonably quickly.

Figure 7.2. The “Barnett (survival) Curve”.

(Barnett, PW. 1962)

In 1962, Barnett published an empirical predictive survival graph based on Molnar's original (Fig.7.2). His expanded six hour time axis made his curve more user friendly and, to overcome the uncertainty of the grey area on the border of Molnar's original single curve, he substituted two curves: one delineating a relative "safe" zone, the other a "lethal; 100% expectancy of death" zone. The large area between these two curves was labelled "marginal; 50% expectancy of unconsciousness which will probably result in drowning".

In 1969, Keatinge proposed guidelines based on experience of laboratory experiments and immersion incidents. Both experimental data, and case histories of shipwreck and aircraft survivors, were employed by Golden (1976) in the production of a curve showing the estimated “50% survival times” in cold water, i.e. the survival time of the "average" individual.

The most recent contribution to this controversial area comes from the still ongoing, UK National Immersion Incident Survey (UKNIIS) (Oakley & Pethybridge, 1997). This is a voluntary reporting scheme, begun in 1990, with the aim of validating the various predictive survival curves described above. Information relating to persons rescued, predominantly from the sea, is forwarded to the authors by some of the various rescue organisations involved.

In 1975, Hayward and his colleagues were among the first to produce a mathematical formula to calculate survival times for cold-water immersion victims. This was derived from an analysis of the cooling rates encountered in 15 young, fit, lightly clothed volunteers, immersed in cold water (5° - 18°C (41 -64°F)). Their cooling rates were mathematically extrapolated to a temperature at which it was considered death would inevitably occur (30°C (86°F)). By implication, if rescue was not achieved before that time, survival would be unlikely.

Figure 7.3. Mathematically derived curves showing estimated survival time (time to an arterial temperature of 33°C (91°F)), for people in cold water: effect of external (clothing, Clo) and intrinsic (subcutaneous fat) insulation on body cooling rate.

Curve A = 0.06 Clo. Naked, thin man.

Curve B = 0.33 Clo. Thin man wearing an uninsulated dry suit.

Curve C = 0.06 Clo. Naked, fat man.

Curve D = 0.33 Clo. Fat man wearing an uninsulated dry suit.

Curve E = 0.70 Clo. Thin man wearing insulated dry suit.

Curve F = 0.70 Clo. Fat man wearing insulated dry suit.

(Adapted from Hayes & Cohen, 1987)

Subsequently other, and more complex, engineering-based mathematical models have been employed to estimate survival time and recommend suitable level of clothing insulation (Wissler, 1981; Hayes & Cohen, 1987; Tikuisis et al, 1988). Included in these have been mathematical models of the human thermoregulatory system. Figure

7.3 shows the output from one such model. Since this version of the model was produced it has been through several iterations that have altered the predictions somewhat. During one of these the “lethal” arterial temperature was increased from 33 (91°F) to 34°C (93°F). Again, such models have largely been based on laboratory studies of young healthy males, supplemented, to a limited degree, by information from animal work and including “adjustments” to produce predictions which are closer to those observed in real life.

Thus, the two main sources of the information used to estimate “survival times” in cold water are, reviews of actual emergencies, and laboratory experimentation supplemented by mathematical manipulation and extrapolation. Whatever the source of the data, the various predictions tend to agree more closely at very cold-water temperatures, and vary more as water temperature increases (Tables 7.1 & 7.2). This is because at the coldest temperatures, the various physiological factors that might cause differences between individuals are overwhelmed by the cooling power of the environment. In warmer water temperatures these factors are more likely to be a source of variation between individuals.

| Water Temp | Molnar | Hayward | Golden | Tikuisis |
|--------------------|---------------|----------------|---------------|-----------------|
| 5°C (41°F) | 1 | 2.2 | 1 | 2.2 |
| 10°C (50°F) | 2.2 | 2.9 | 2 | 3.6 |
| 15°C (59°F) | 5.5 | 4.8 | 6 | 7.7 |

Table 7.1. *50% Survival times (hours) for lightly clad males, from various authors.* (From: Oakley & Pethybridge, 1997)

| Water Temperature | Molnar | Keatinge | Nunnely & Wissler | Allan | Lee & Lee |
|--------------------------|---------------|-----------------|------------------------------|--------------|----------------------|
| 5°C (41°F) | 2.3 | 0.9 | 1.1 | 1.5 | 1 |
| 10°C (50°F) | 4 | | 2.6 | 2.5 | 3 |
| 15°C (59°F) | | 4.5 | 3 | 9 | 7 |

Table 7.2. *Immersion time (hours) resulting in “likely death” from various authors. Lightly clad males.* (From: Oakley & Pethybridge, 1997)

Sources of Error in the Estimation of Survival Time

Several factors make the prediction of survival time in cold water difficult. These include: the ambiguity of the definition of survival time; the lack of well-documented data from actual incidents; the consequent reliance on extrapolation of data from innocuous laboratory-based exposures; and individual variability. However, above all of these are the variability in sea state, and the exclusion of the possibility of resulting death from drowning (see chapter 5). Some of these issues are considered below.

a. Interpretation

One common source of error is a misinterpretation of what is represented by the curve drawn on a graph depicting survival time. As we saw in the previous section, this curve can represent: a limit of tolerance; a relative safe zone; a lethal zone; a marginal zone; or estimated 50% survival time. Other authors provide information relating to a “good prospect of survival”. The 50% survival curve has been mistakenly taken to represent the time that an individual would have a 50:50 chance of survival, rather than the survival time of 50% of individuals. Furthermore, it is often forgotten that this time theoretically exceeds the survival time of 50% of individuals.

The problems outlined above are exacerbated by replication of the various survival curves without the associated explanations and caveats, and by the ill-conceived formulation of “hybrid” curves.

b. The lowest temperature compatible with life

The prediction of survival time in cold water requires an *a priori* assumption about the deep body temperature at which death occurs. The temperatures chosen have varied between a “deep body temperature” of 28°C (82°F) and a “blood (arterial) temperature” of 33°C (91°F). Inherent within this assumption, is a second about the cause of death on immersion.

Data obtained by the infamous Nazi researchers at Dachau during WW II suggested that during immersion in calm water, under laboratory conditions, death is due to cardiac rather than a respiratory causes. The lethal body temperature for people immersed in cold water was reported to be in the region of 24-26°C (77-81°F), although cardiac arrest from ventricular fibrillation was frequently encountered below 28°C (82°F). Concerns over the ethical and scientific accuracy of these data cast doubt on their precise veracity but, when taken together with anecdotal accounts from many different sources, it can be concluded that most of the reported Dachau data are reasonably accurate. However, many individuals have survived much lower deep body temperatures following accidental exposure to cold; the current record being a rectal temperature of 13.7°C (56.6°F) in a young female skier (Gilbert, et al. 2000).

Thus, even a cursory glance at the literature shows that a single “lethal” deep body temperature does not exist, and the temperature thought to be “incompatible with life” can vary greatly between individuals.

The temperature selected by those wishing to predict survival time is generally higher than 25°C (77°F). This is because some allowance is made for the fact that at relatively high deep body temperatures, 33°C (91°F) in some models, local cooling of the more superficial muscles and nerves inhibits their function to the point where self-help is limited. This can result in death by drowning before death from hypothermic cardiac arrest (Chapter 6). However, the temperature at which this “incapacitation” occurs is potentially just as variable as the “lethal” temperature. Therefore the selection of the lowest body temperature compatible with life remains one of the major potential sources of error in the estimation of survival time.

This error is compounded by the fact that most predictions of survival time ignore the initial and short-term responses to immersion (Chapter 4). The evidence presented in previous chapters suggests that drowning, consequent to cold shock, represents the

major risk on immersion in cold water (< 15°C (59°F)); and in very cold water (<5°C (41°F)) survival time for many is measured in minutes rather than hours.

c. Determining the rate of cooling

The estimation of survival time on the basis of laboratory experimentation requires an extrapolation to be made beyond data that can be obtained from ethical human experimentation. To do this, some authors have simply extended the rate of cooling established in the laboratory down to an assumed “lethal” temperature. There is some evidence to support this approach from Nazis experiments at Dachau with poorly insulated individuals in stirred, very cold water. In such a situation heat losses are too great to be offset by metabolic heat production.

However, in circumstances where heat losses can be balanced by heat production (shivering), the assumption of a linear rate of fall of deep body temperature to a lethal level is erroneous. Such circumstances can occur in: survivors wearing effective immersion suits; those in liferafts; or even in some lightly clothed individuals in moderately cool water (about 20°C (68°F)), provided they have sufficient subcutaneous fat. The available experimental evidence suggests that in such circumstances many individuals will, after an initial fall in deep body temperature, generate enough heat through shivering to enter thermal balance, at least for some period of time. In this case a simple linear extrapolation is unlikely to provide an accurate estimation of survival time (Fig 7.4). If such a model is used during the initial fall in deep body temperature, before thermal balance is achieved, it will provide a gross underestimation of survival time. In contrast, if it is used when thermal balance has been achieved, an indefinite survival time will be predicted. In reality, in this situation survival time will be determined by the duration for which shivering can match heat lost (shivering endurance).

Figure 7.4. *Diagrammatic representation of the error associated with employing linear extrapolation.*

Given that the stabilisation of deep body temperature may occur at a temperature lower than that, which is ethically permissible in human experimentation, it is impossible to have complete confidence in linear extrapolations from laboratory data.

d. Mathematical Models

Mathematical models were originally designed to simulate the human thermoregulatory system in an effort to explore and understand its mechanisms and their interaction. Some of these models have been amended to estimate and prescribe the insulation requirement for immersion protective clothing to be used in cold water. Finally, some models have been used/misused to predict how long someone will survive following immersion in cold water. It is these models that are used by many search and rescue organisations.

These prescriptive and predictive models are largely based on the results obtained from relatively innocuous laboratory-based experiments, in which subjects were cooled by one or two degrees Celsius (3-4°F). The models perform reasonably well when validated against results obtained in such conditions. However, the “correction factors” which often have to be incorporated within them in order to make them “fit” experimental data, are indicative of the inherent difficulty associated with modelling

something as complex as the human thermoregulatory system. Given the level of understanding of this system, and its interactions with the macro and microenvironment, there is no reason to believe that a definitive mathematical model of thermoregulation can yet be produced.

There have been several independent evaluations and reviews of models. These have been undertaken either theoretically, or by comparison of mathematically predicted responses with those obtained during experimentation. The general conclusion reached has been that the prediction of responses in cold environments is poor; that models are only suitable for simulating a very limited range of conditions, and should not be used to extrapolate beyond the range of knowledge. That is, models should be used as an investigative rather than predictive tool. In any case, even if a model could accurately predict the impact on survival time of variables such as sea state, gender and age, in a real accident knowledge about the survivor may be limited to gender.

Finally, model predictions are almost exclusively based on the response of lightly clothed, young, Caucasian males, undertaking immersions in relatively calm cold water. Perhaps the greatest problem facing those that try to estimate survival time in cold water, with or without complex models, is the variability that results from differences in cooling between situations and individuals. Some of the factors causing this variation are briefly reviewed below.

e. Sources of variation

i. Sea state, clothing and leakage

Conditions in open water are usually much more severe than those encountered under controlled experimental conditions. Two consequences of this are an increase in the risk of drowning and, for those wearing immersion “dry” suits, an increase in water leakage.

As mentioned, the single most important omission from the predictions of survival is the variability due to sea state. The danger of drowning because of wave splash was discussed in the previous chapter.

Wetting significantly reduces the insulation provided by clothing. Uninsulated dry suits keep the body warm by keeping the normal clothing worn beneath them dry. This insulation is reduced if the clothing becomes wet by leakage (Hall & Polte, 1956) or cold-induced urination. Average water leakages of 500 mL to 1 L have frequently been recorded during laboratory-based, relatively innocuous, immersion experiments. Wetting by this volume will reduce clothing insulation by 30-40%. This equates to a reduction in the external immersed insulation provided by an uninsulated suit from 0.33 Clo to 0.16 Clo. The impact of such a reduction on deep body cooling and survival time in humans has been estimated using mathematical models. With the caveats noted above and below, this decrease in external insulation is predicted to result in a reduction in estimated survival time in water at 10°C (50°F) from just over three hours to just under 2 hours (Hayes & Cohen, 1987). Some international specifications for “survival suits” have, as a consequence, been based on restricting water ingress to within 200 mL during leak testing.

Large volumes of water leakage will also decrease the buoyancy of a clothing assembly and increase the threat to the airway by reducing the mouth to water distance.

Survival curves make no allowance for where on the body leakage and wetting occur. However, this can make a large difference to the consequent change in deep body temperature. A 500 mL leak over the limbs has little impact on the rate of fall of deep body temperature, whereas a corresponding leak over the torso significantly increases it. This is because with cooling, heat loss from the limbs is minimised as internal insulation is maximised by vasoconstriction. Thus, in an immersed individual most of the heat loss from the body is from the torso, especially the back of the torso due to hydrostatic pressure reducing the clothing thickness and, therefore, insulation in this area. This regional effect of water leakage is not observed when clothing is tested on thermal manikins rather than humans, because manikins cannot vasoconstrict. It is also not recognised in the survival curves that incorporate an effect for leakage, because manikin data have been used to determine this effect.

Largely due to increased water leakage and convective heat loss, the insulation provided by dry suits can be reduced by as much as 33 -100% when worn in open turbulent water compared to the laboratory. As a consequence, the time of “*useful consciousness*” may be much shorter than anticipated in such situations, even in those wearing specialised garments. This, in part, explains the “surprisingly poor performance of immersion suits” reported in some fatal accident inquiries.

Wearing waterproof or hydrophobic undergarments reduces the impact of wetting, because hydrophobic material retains more of its thermal insulation when wet. Insulated suits incorporating waterproof insulation in their construction are therefore least affected by water leakage. They also remove the requirement for the wearer to provide his own insulation but, because they also impair heat loss in air, can be uncomfortable to wear in hot conditions, especially when working. An insulated suit, properly worn and functioning, can reduce the rate of fall in deep body temperature by a factor of about seven during cold water immersion, when compared with normal everyday clothing (Chapter 3).

Finally, even if it is known that there is specialised protective clothing available to a survivor, a rescue co-ordinator cannot be confident that it is not leaking, or whether the victim is even wearing it, but must assume so.

Figure 7.5. *Times of useful consciousness (deep body temperature 35°C (95°F)) of individuals immersed in cold water in different clothing assemblies under laboratory conditions. (1 Clo = 0.156°C/sq.metre/watt; or the insulation provided by a business suit and standard undergarments).*

ii. Buoyancy and Airway protection

For the survivor the most common sources of buoyancy are a lifejacket, an immersion suit, or parts of the sinking vessel and associated flotsam. In a recent survey (UKNIIS) of immersion incidents, death occurred in 5 (3%) of those wearing lifejackets and 45 (10%) of those not wearing lifejackets. However, this latter percentage figure may be much larger as the survey was directed primarily at those

who survived, and only included a small proportion of those who died. Lifejackets save lives by helping to keep the airway clear of the water during both consciousness and unconsciousness. Unfortunately, as already mentioned in chapter 6, immersion suits and lifejackets have tended to be developed, specified and tested separately. This separation has prevented the requirement for a major re-design of lifejackets to be worn with immersion suits.

The question of compatibility is important, as most commercially available suits will float the wearer in a horizontal attitude because of the air trapped within the garment. While this flotation attitude is thermally beneficial - halving the surface area exposed to the water and reducing hydrostatic compression - it does present some major disadvantages in relation to the lifejacket. Firstly, the buoyancy chambers, situated over the front of the chest, remain well clear of the water and contribute little to buoyancy when the wearer is lying on his back. Secondly, the air trapped in the suit is capable of maintaining the unconscious wearer in a facedown flotation position despite having inflated buoyancy chambers over the front of the chest (some lifejackets have asymmetric chambers to facilitate automatic self-righting in such a situation). Thirdly, a horizontal flotation angle tips the back of the head into the water. Many lifejackets fail to alleviate this problem because their collars buckle under the weight of the head and reduce the mouth to water distance. Trials using a model unconscious human being (manikin), wearing a widely used immersion suit/lifejacket combination in steep waves of just over one metre, showed that the mouth was submerged for just under one third of the test (RGIT, 1988). Immersing the back of the head has the added disadvantages of cooling a part of the body which is critical for survival (the brain stem), as well as an area which readily loses heat and therefore leads to accelerated cooling of the body.

Thus as well as being thermally undesirable, a horizontal flotation angle may facilitate drowning. The addition of a splashguard may prove helpful in these circumstances, often undervalued due to poor design, an effective splashguard can be an essential piece of protective equipment. However, this does not remove the requirement for integrated and compatible lifejacket and immersion suit design. Such an approach is essential to ensure that the head is kept well clear of the water.

The above, as well as poor fit and lifejacket chamber and harness design, help to explain why some of those wearing lifejackets still drown, and do not achieve expected survival times.

It cannot be assumed therefore, that the survival time of someone wearing an immersion suit and lifejacket is necessarily a great deal longer than that of a survivor with a lifejacket but without an immersion suit. The findings of fatal accident inquiries abound with stories of people dying after 1-2 hours, despite wearing immersion suits approved to a standard that suggested a minimum of three hours survival in cold water. How the suit is worn, how it functions, how much and where it leaks and how it integrates with other survival equipment, in particular the lifejacket, will all influence survival time. This situation will not be improved until the various pieces of equipment provided for those at risk of immersion are regarded as a single "integrated survival system" and specified and tested accordingly.

The buoyancy provided by upturned hulls, large pieces of driftwood and so on, offer the opportunity for the survivor to get partially or completely out of the water. Despite the fact that it often “feels” colder out of the water than in it, and frequently air temperature is lower than water temperature, there is no circumstance in which a survivor would not be better out of cold water. On average the cooling rate on a raft, even on one where the survivor is exposed to the wind, is less than half of that observed in the water (Steinman et al., 1987).

iii. Gender and Size

As fat is a good insulator, when all other things are equal, the average female should cool more slowly than the average male, because females have about 10% more body fat. However, if a male and female with the same amount of body fat are immersed, generally, the female will cool more quickly than the male because females have a higher surface area to mass ratio than males, and a smaller shivering response. Thus females have a smaller heat producing mass and a relatively larger surface area over which to lose heat. Children of either gender cool much more quickly than adults, as they have a large surface area to body mass ratio as well as lower levels of body fat.

iv. Exercise

The effect that exercise can have on deep body temperature and consequent survival time is dependent on several factors including the:

- intensity of the exercise performed;
- type of exercise performed;
- water temperature;
- amount of water movement;
- physical characteristics of the survivor,

and

- clothing worn.

In general, whole-body exercise in water cooler than 25°C (77°F) will accelerate the rate of fall of deep body temperature compared to that seen when remaining static. This is because the movement associated with exercise stirs the water around the body, disturbing the boundary layer and increasing convective heat loss. This effect is less pronounced if the water is already moving around the body rather than still.

Exercise also increases the blood flow to the limbs. At rest, the insulation of the body is provided by skin, fat and unperfused muscle (resting muscle has minimal blood flow). Because the body contains a lot of muscle, when it is unperfused it can provide 70% of the total body insulation of a resting person in cold water. At an exercise intensity of about 150W (about twice resting levels of activity) the blood flow to the working muscles, normally those in the limbs, increases. The insulation provided by this muscle is lost, leaving only the fixed insulation of skin and fat. When muscle blood increases the amount of heat that is delivered to the limbs also increases and is lost to the surrounding water. The high surface area to mass ratio of the limbs makes them ideally suited to transfer heat.

In contrast to whole-body exercise, leg only exercise can keep deep body temperature higher in cold water than that seen during resting immersions. This suggests that the arms are a major area of heat loss in cold water. This seems logical given that the arms have a larger surface area to mass ratio than the legs, a smaller conductive

pathway from the centre of the limb to the surface, and a smaller heat producing muscle mass. In addition, when they are not used for exercise, the arms can oppose the torso and help insulate it.

Increases in internal (fat) and external (clothes) insulation can reduce and, in the case of specialised clothing, even reverse the detrimental effect of exercise in cold water. In the case of clothing, this is because a dry suit, which does not leak, essentially returns the wearer to an air environment.

We saw in Chapter 4 that swimming ability is greatly impaired in cold water. It is therefore recommended that if a survivor has to exercise in water he uses leg-only exercise, and keeps his arms as still as possible and close to his torso. In practice, the arms may have to be used in order to keep the back to the oncoming waves (Chapter 6).

v. Posture in the water

It follows from the above that a good posture to adopt in cold water is one that minimises both movement and the surface area of the body exposed to the water. The natural position adopted as people become cold and muscles become more spastic, is a flexed “foetal” position. Hayward et al. (1975) have recommended that such a posture should be consciously adopted while awaiting rescue in order to conserve body heat. They have termed the posture “HELP” (Heat Escape Lessening Posture; Fig. 7.6). However, it is a difficult and impractical posture to try and maintain in an open seaway. Furthermore, the recommendation was based on the assumption that both the groin and axilla (arm pits) were areas of high heat loss. This has subsequently been shown to be exaggerated.

Hayward et al (1975) have also recommended that groups of survivors should huddle together in a circle in the water (the “HUDDLE” position; Fig. 7.6). It is claimed that this will help reduce the rate of heat loss, as well as improve morale and make location easier. Again, this advice may be correct for the experimental tank, calm inland waterways or lakes, but in an open sea it will make life very difficult for the survivors on the downwind side of the group, as they will be facing the oncoming waves and have to contend with constant wave splash (see anecdote on sea canoeists in chapter 6).

Figure 7.6. “HUDDLE” & “HELP” postures (not recommended for open sea) from Hayward et al. (1975)

vi. Shivering response

Like other regulatory systems of the body, the thermoregulatory system does not act in isolation. It is interconnected with, and influenced by, many of the other regulatory systems of the body. It is these influences that explain some of the large variation observed between the shivering responses of different individuals. Indeed, some authors have categorised subjects as “shiverers” and “non-shiverers” on the basis of their metabolic response to the same cold stimulus. The underlying causes of this variability include: inherent differences in the sensitivity of the metabolic response; age; gender; morphology; fitness; illness and injury; nutritional state; concentration of blood alcohol or other drugs; blood sugar concentration; ambient carbon dioxide levels; ambient oxygen levels; previous exposure to cold (cold habituation); and

environmental pressure (Table 2.1). These factors can influence both the threshold for the initiation of the metabolic response and its intensity. For example, age, decreased blood glucose concentration (“*hypoglycaemia*”) and cold habituation all delay the onset of shivering and reduce the sensitivity of the response. These changes result in a faster rate of fall of deep body temperature in the cold.

While it is relatively easy to calculate heat loss in certain well-defined situations, the numerous sources of variation make it extremely difficult to predict the intensity of the shivering response for a given individual, and its consequence for deep body temperature and survival time.

Shivering, like all metabolic activity, consumes energy and can only continue while the substrates required to fuel it are available. When these are exhausted, shivering will be attenuated and the rate of body cooling will increase. There is little information on the length of time for which shivering can be maintained at a given intensity. This is important because it will determine survival time in situations where thermal balance can be maintained if shivering is present. Even the most advanced mathematical models are poor at estimating shivering endurance; models have predicted the cessation of shivering due to depletion of muscle sugar content after 4 hours in water at 10°C (50°F). In contrast, the evidence from human studies is that sub maximal shivering can continue for at least 16 hours without food, and several days if survival rations are available (400kcal/day glucose plus 568 mL water/day).

vii. Seasickness

Seasickness not only increases dehydration, it can also increase the rate of heat loss in a cool situation. This occurs due to a reduction in the intensity of the cold vasoconstrictor response and increased evaporative heat loss caused by generalised sweating. Seasickness also has a significant detrimental effect on morale and the mental state of survivors (Chapter 10).

viii. Mental state

Evidence from a number of sources emphasises the beneficial effect that a positive mental attitude can have on the “*will to survive*”, and the determination to do what is necessary to survive. A little knowledge can help individuals retain this positive mental state. For example, the knowledge that almost all “dry suits” leak a little in a real survival situation may prevent the depression and panic that comes with the belief that you have the only leaky suit. Doing the right things in a liferaft to avoid seasickness can prevent what is a major cause of misery in the survival situation. Despite taking anti motion illness medication, if you are still seasick it is essential to understand that you must drive yourself to adopt a positive attitude, and not simply surrender to despair.

PREDICTING SURVIVAL AND SEARCH & RESCUE TIMES

It is apparent that the existing predictive survival curves do little other than remind those that need reminding, that survival in cold water is time limited. Guidelines based on the analysis of accidents, together with laboratory based experimental evidence, show a clear correlation between water temperature, body cooling and survival times. However, it is also apparent that because of the vast array of factors

that can influence survival time in cold water, this time can be measured from seconds to days. Predicting survival times in immersion victims is not a precise science; there is no magic mathematical formula to determine exactly how long someone will survive, or how long a rescue search should continue. As a consequence, the Search and Rescue (SAR) co-ordinator must make some unenviable decisions based on the best information available and a number of assumptions. To cover themselves they must extend the search times beyond that which they can reasonably expect anyone to survive. Occasionally they will get it wrong and then, in the event of litigation, it will be up to the Law Courts to make a judgement on the definition of "reasonable expectation". But as a general rule of thumb it is considered prudent for the recommended search times to be in the region of at least three to six times the predicted 50% survival times.

Thus in water at 5°C (41°F), the 50% survival time for a normally clothed individual is estimated to be in the region of 1 hour, with a recommended search time of 6 hours. The corresponding times for 10°C (50°F) are 2 hours and 12 hours. While in 15°C (59°F) the 50% survival time is in the region of 6 hours, with the recommended search time of 18 hours. Between 20°C (68°F) and 30°C (86°F) search times exceeding 24 hours should be considered, and several days above 30°C (86°F).

Near naked swimmers would be at the lower ranges of these times. In calm water there may be an exceptional individual (someone who is very fat and fit) who will exceed expectations. If it is known that the victim is such an individual, consideration should, exceptionally, be given to extending the search times from 3-6, to 10 times the predicted 50% survival time.

For inshore accidents, survival times may be less due to breaking water and adverse currents. However, consideration must be given to the possibility that the inshore survivor managed to get ashore. Consequently, the limiting effects of cold water-cooling will no longer be the only consideration, and the search must be continued until such time as the shore adjoining the coastline, allowing for tidal drift, has also been thoroughly searched.

Offshore it is reasonable to expect that individuals will be better equipped to survive, and have access to appropriate protective clothing, lifejackets and possibly liferafts. Consequently, search times for them should be at the upper limits of those expected (10 times predicted 50% survival time), unless obviously adverse conditions prevail.

CHAPTER SUMMARY AND RECOMMENDATIONS

- **The potential usefulness of accurate estimations of survival time in cold water have led many since WWII to produce predictions of survival times.**
- **Predictions have been based on accidents and laboratory studies supplemented by mathematical manipulation and extrapolation.**
- **Sources of error and variation have meant that the prediction of survival time has remained more of an art than a science.**
- **Sources of error include:**
 - **The interpretation of survival curves;**
 - **The assumption of a lethal body temperature;**
 - **Methods used to estimate rates of cooling;**

- Use of mathematical models;
- The assumption that death is due to hypothermia.
- Sources of variation in survival times include:
 - Sea state;
 - Effectiveness of protective equipment being used;
 - Personal factors, e.g. gender, size, fitness, health, age, shivering response;
 - Posture and exercise in the water;
 - Seasickness and mental state;
 - Water and food availability.
- Accepting the above limitations, 50% survival times for normally clothed, young, fit and healthy individuals approximate: 1 h in 5°C (41°F) water; 2 h in 10°C (50°F); and 6 h in 15°C (59°F).
- Search time should be at least three to six times the predicted 50% survival time. In exceptional circumstances e.g. favourable weather conditions; well protected survivors, etc., search time should be extended to at least 10 times the 50% survival time.

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