J roy nav med Serv 1995; 81: 101-107

Debating point

Immersion fatalities: Hazardous responses and dangerous discrepancies

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Based on a paper presented at the SINTEF UNIMED 'Thermal Physiology and Survival Clothing' meeting held in Aberdeen in 1993.

Abstract

In this paper the following question is addressed: 'Why, given the plethora of standards, specifications and guidelines for immersion protective equipment, are lives still being lost at sea and fatal accident enquiries questioning the quality of such equipment?'

In attempting to answer this question, consideration is given to the extent to which both the possible prevailing environmental conditions, and the physiological responses they evoke, are recognised in the design, selection and evaluation of immersion protective equipment. The hazardous responses associated with immersion in cold water are briefly reviewed and the value and relevance of some of the existing tests of immersion protective clothing are considered.

It is concluded that: i. when standards, policies and tests for the selection and use of immersion protective clothing are being formulated, consideration should be given to all of the hazardous responses associated with immersion; ii. it should be recognised that the performance of immersion protective equipment during an accident may be significantly inferior to that predicted by routine testing for certification.

The area of survival in the sea is truly multi-disciplinary, bringing together experts from a wide variety of fields including policy-making, manufacturing, industry and science. In *Figure 1* the consequences of both good and poor lines of communication between scientists, policy makers, regulatory bodies and manufacturers of immersion protective equipment are presented.

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It can be seen that it is the standards, specifications, regulations and guidelines of the regulatory bodies which will determine the level of performance of immersion protective equipment. Manufacturers are unlikely to produce the best equipment they can *per se*, but will produce equipment sufficient to comply with the relevant standards. This is understandable given the competitive nature of the protective equipment market and the costs associated with producing unnecessarily advanced products.

Thus the quality of the standards used to evaluate protective equipment becomes a critical factor. In *Figure 1* it is suggested that such standards can be significantly weakened if they do not address all the hazards against which an immersion victim should be protected, or if they fail to evaluate or predict performance in the full range of potential environmental conditions. It is when either or both of these weaknesses exist within a standard that protective equipment which complies with that standard can perform 'surprisingly' poorly during an emergency.

It is worth noting, that the alternative to surprisingly poor performance should not be 'surprisingly good performance', as this also suggests a degree of inaccuracy in the evaluation of the protective equipment. The best that can be achieved by the evaluation of such equipment is that an accurate indication is obtained of its performance during an emergency. This will then allow those with the responsibility for policy-making or purchasing such equipment to make a more informed choice.

An important first step in producing a standard is, therefore, to identify the hazardous responses associated with immersion in cold water. In the following section these responses are briefly reviewed.

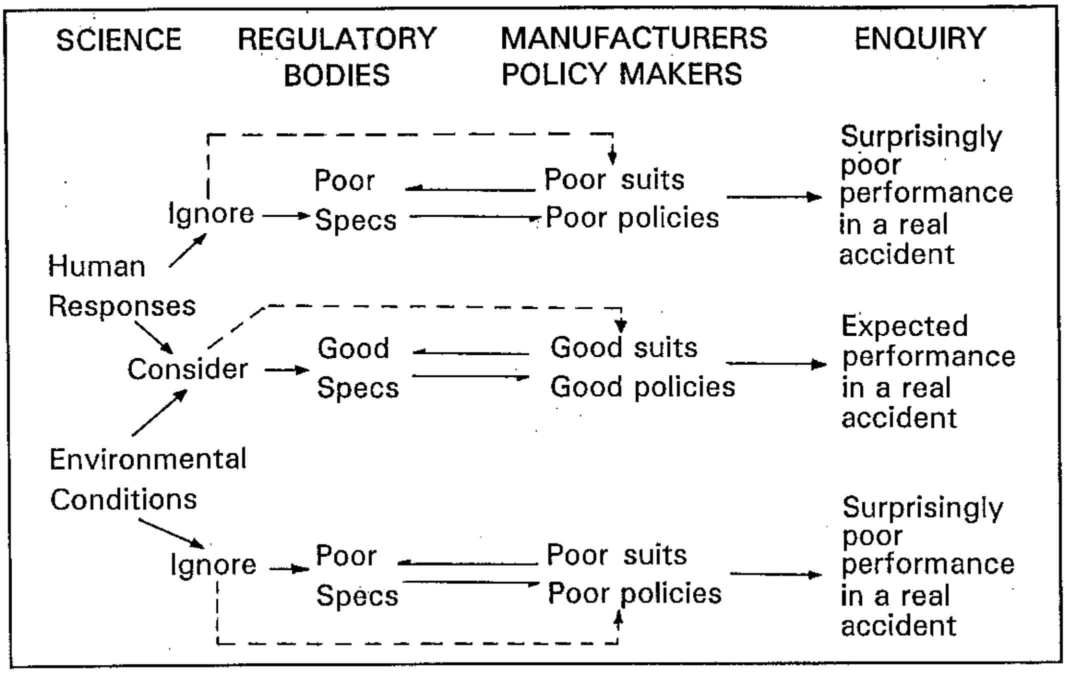

Figure 1. Relationship between the groups involved in survival in the sea.
Note: 'Specs' = specifications, regulations, standards and guidelines.

HAZARDOUS PHYSIOLOGICAL RESPONSES TO IMMERSION IN COLD WATER

The design of immersion suits, their performance specifications, the tests and standards used to evaluate them, and policies for their use are still primarily influenced by the belief that the major threat is hypothermia, or a fall in core temperature. Thus, the role of immersion suits is generally thought to be to delay the onset of hypothermia.

Despite the vast amount of attention which has been given to hypothermia, and the efforts that have been made to protect against it, experimental evidence suggests that other responses can present a significant threat to life. Golden and Hervey[1] have described four phases of immersion associated with particular risks. These are:

i. Initial immersion

There is now a large body of anecdotal[2], statistical[3,4] and experimental evidence[5-8] to suggest that the initial responses to immersion in cold water are potentially extremely dangerous and are responsible for the majority of the annual open water immersion deaths in the UK.

These responses, given the generic term 'cold shock', are thought to be initiated by a sudden fall in skin temperature, they peak within the first 30 seconds of immersion and adapt over the next 2-3 minutes. The responses include tachycardia, hypertension and an inspiratory 'gasp' which decreases breath-holding capability (*Figure 2*). Most individuals hyperventilate and tetany has been reported in the laboratory.[9] The percentage of subjects able to achieve any given average maximum breath-hold time when submerged wearing immersion protective clothing is presented in *Figure 3*.

Cold shock constitutes a serious threat to immersion victims, particularly those who need to consciously suppress their breathing following immersion in choppy water or submersion in a sinking craft. Maximum breath-hold times of less than one second have been reported following immersion of naked individuals in cold water[10] and an average maximum breath-hold time of 25 seconds has been reported for 12 subjects submerged in water at 5° and 10°C wearing specialist protective clothing.[11] It is the shortfall between this time and that thought necessary to make an underwater escape from a ditched and inverted helicopter which provides the rationale for some form of emergency breathing aid to

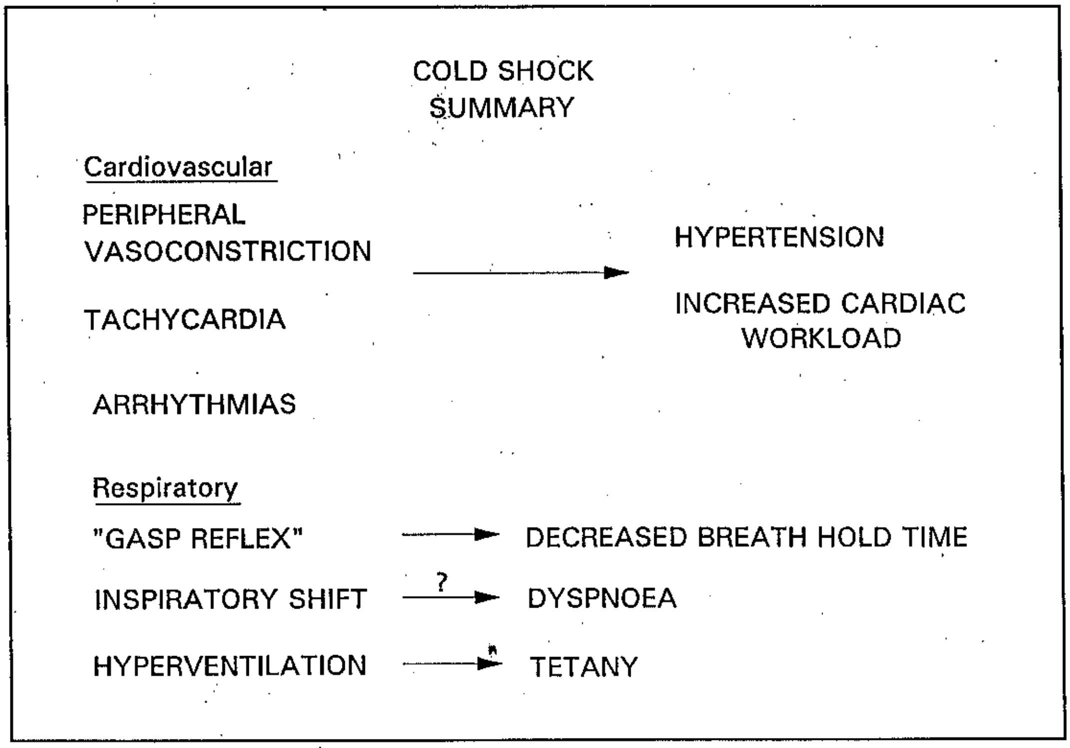

Figure 2. Summary of the initial responses to immersion in cold water.

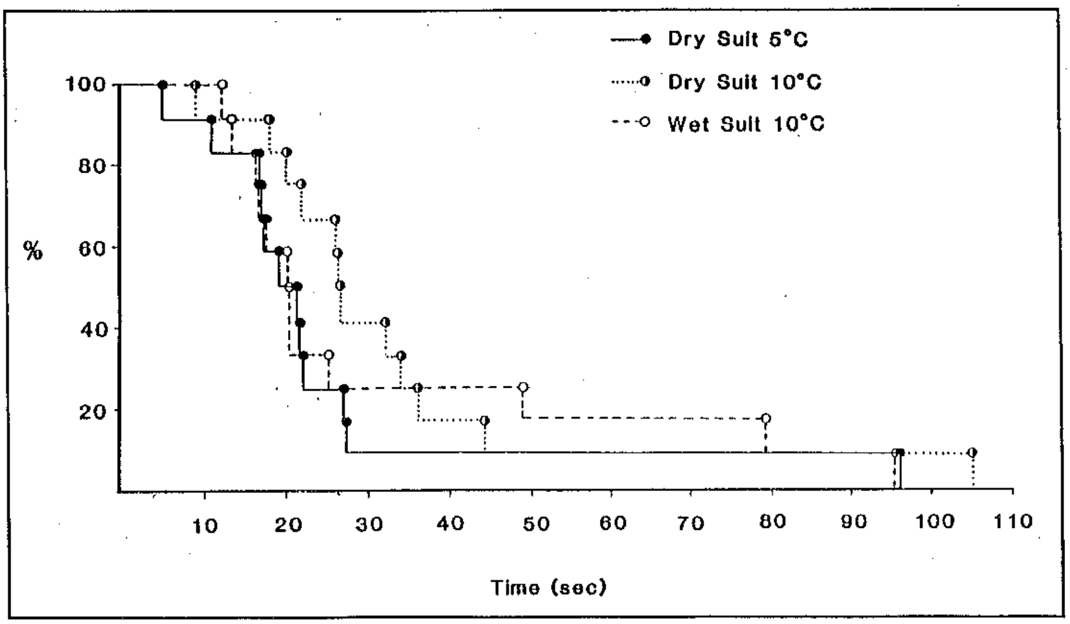

Figure 3. The percentage of subjects able to achieve any given maximum breath-hold time when wearing dry or wet suits in water at 5° and 10°C (n=12).

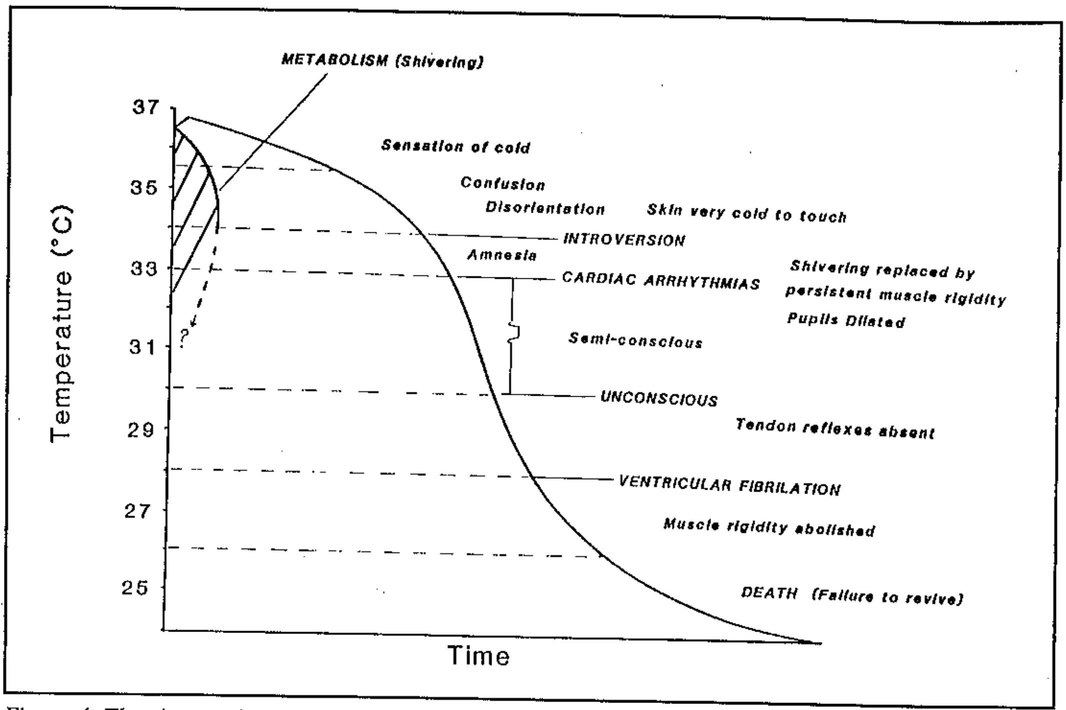

Figure 4. The signs and symptoms of hypothermia (based on Golden[14]).

be added to the list of equipment provided for helicopter passengers and crew.

ii. Short-term immersion

The main problem associated with immersion lasting 3-30 minutes is keeping the airways clear of the water; even good swimmers are often unable to swim for more than a minute or two in very cold water[12, 13]. This may be due to the respiratory and cardiovascular responses already discussed and/or peripheral cooling which can impair neuromuscular function.

iii. Long-term immersion

The signs and symptoms of hypothermia are presented in *Figure 4*.[14] In general, after about 30 minutes of immersion, hypothermia can, for the first time, become a problem. The threat to life may arise from hypothermia directly, that is the body temperature falls to untenable levels or, for the victim without an effective lifejacket, from drowning after incapacitation and unconsciousness arising from less severe hypothermia.[14]

iv. Post-immersion

Death may occur during or following rescue. On average about 20% of immersion fatalities occur just prior, during or just following rescue ('circum-rescue collapse'[15]). A number of these deaths have been attributed to the 'after-drop' of the body core temperature, observed following removal from cold water.[16] However, Golden and Hervey[1] found no 'after-drop' in the temperature of the central venous blood of pigs following cold water immersion. They suggested that a sudden fall in the temperature of the heart due to the return of a 'cold bolus' of blood from the cooled periphery was unlikely to constitute the mechanism of post-immersion death, especially in individuals whose core temperature was high enough for them to be conscious on rescue.

As an alternative hypothesis, Golden and Hervey have suggested that in the hypothermic individual, whose regulatory responses have been compromised, the loss of the hydrostatic assistance to circulation (up to 30% of cardiac output) on removal from the water may lead the collapse of arterial pressure and, as a consequence, cerebral ischaemia, coronary insufficiency and myocardial hypoxia. The problem is thought to be compounded if the victim is lifted vertically from the water as in this situation venous pooling, under the influence of gravity, will further reduce cardiac output. Lifting individuals from the water in a horizontal attitude would, in theory therefore, be beneficial.

It is concluded that when standards, specifications and guidelines for immersion protective equipment, and survival policies are being formulated, consideration should be given to all of the hazardous responses associated with immersion and not just those which result in hypothermia. Currently, this does not appear to be the case: a review of standards, specifications and guidance notes for immersion protective clothing[17] has revealed that none, including those for helicopter passengers and crew, has a specific performance objective or type-test to establish the level of protection provided against the initial responses to immersion in cold water.

Acceptance of the threat presented by cold shock could have profound implications for the estimation of survival time, the policies formulated for the use of immersion protective equipment and the type of equipment recommended. For example, even in situations where rescue times are thought to be very short, knowledge that the cold shock response is at its greatest during the first 30 seconds of immersion would necessitate the provision of an 'appropriate' immersion suit and lifejacket for those at risk of even the shortest periods of immersion. Furthermore, the criteria for 'appropriate' suits may alter; as the cold shock response is initiated by sudden falls in skin temperature, suits which do not incorporate watertight wrist and neck seals are likely to possess an inherent disadvantage when it comes to protecting against this response. Currently, many wet suits and constant wear work suits do not incorporate such seals.

ENVIRONMENTAL CONDITIONS DURING AN ACCIDENT COMPARED TO THOSE PRODUCED DURING TESTING

It is clearly critical that the performance objectives and tests contained within standards give an accurate indication of the protection which equipment might provide during an emergency. To do this, tests must either recreate the tasks which may have to be undertaken and the environmental conditions which may exist during an accident, or provide a reliable and valid way of predicting performance in such situations. If they do not, then there is a danger that 'approved' suits will be inappropriate, or not as appropriate as they might be.

REALISTIC TESTING?

The innocuous nature of many laboratory-based tests of immersion suits has been recognised for some time. Steinman *et al*[18] have noted the effect of sea state on the rate of cooling of immersed clothed subjects. An examination of climatic records for the North Sea reveals that the average wave height falls below the 4-6 metres of sea state 6 during only two months of the year.[19] This contrasts with the 30cm waves achieved during most laboratory-based cold water investigations. The less severe conditions within the laboratory result in slower rates of cooling due to less convective cooling, less 'flushing' of water and, most important of all, lower levels of water leakage.

Leakage of water into an uninsulated dry suit and undergarment wetting, either during underwater escape from a submerged aircraft or during surface survival actions, will reduce the insulation provided by such clothing assemblies.[20,21] Light *et al*[22] reported that during underwater escape dry suit leakage ranged from 46g to 283g; during 20 minutes surface activity it ranged from 177g to 1398g. When the figures for the moisture accumulating in the suits due to perspiration caused by flight conditions were added to those shown above, the potential loss of insulation due to dampening within the dry suits tested ranged from 15 to 50%.

Clearly, the potential exists for laboratory-based tests to over-estimate the performance of immersion protective equipment. This is shown in *Figure 5* where the results of an experiment are presented in which a group of subjects undertook two immersions wearing identical clothing assemblies. The only difference between the two immersions was that in immersion B 15cm waves, periodic surface spraying, a 6 knot wind and an initial 15 second period of submersion were introduced. This relatively mild increase in the severity of the conditions employed during the test resulted in a reduction of about 30% in the estimated survival time provided by the clothing during test B. In both tests the brand new, well fitting, uninsulated dry suit which was worn was an 'approved' suit, which had allowed less than 200g of water ingress during the leakage tests required by various standards. The average leakage

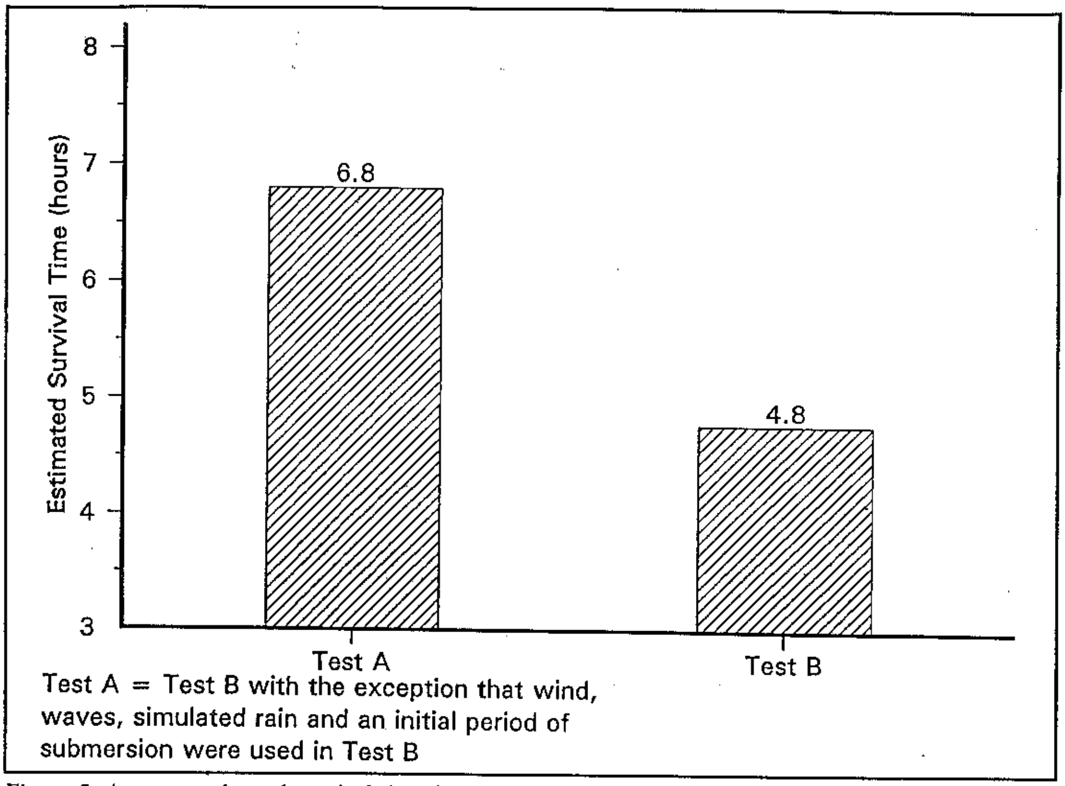

Figure 5. Average estimated survival time for subjects wearing a standard uninsulated immersion dry suit in two sets of conditions in water at 4°C (n=12).

recorded during the first 20 minutes of Test B in the experiments reported above was 1.144 litres.

In addition to the severity of the tests used to evaluate immersion suits, other possible sources of discrepancy in the performance of a suit in a test and during an accident include:

a. The age of the equipment — the equipment used in tests tends to be new whereas that used during an accident may be nearing the end of its useful life and have been repaired many times.

b. That the tests conducted on a suit, e.g. fire protection, water leakage, thermal protection, tend to be undertaken separately and on different suits. In an accident a single suit may have to endure all of these factors and, as a consequence, serial testing may be more representative.

c. That normally, different pieces of protective equipment are worn in combination but these combinations are seldom tested together. The best known example of this is lifejackets and immersion suits which are tested separately and then worn in combination — evidence suggests that the performance seen in isolation can be quite different from that seen in combination.[23, 24] The development of 'integrated survival systems'[25] may help to improve this situation, particularly if specific standards are developed for complete systems.

d. The use of thermal manikins. Recent evidence[26] suggests that although immersion thermal manikins provide accurate measurements of external insulation, caution must be exercised when using the results from manikins to determine the relative value of immersion suits designed for use by humans. This is because manikins give no indication of the effect which variations in regional insulation (by design, or as a result of water ingress) will have on deep body temperature.

CONCLUSION

If the chances of protective equipment performing 'surprisingly poorly' during an emergency are to be reduced both the communication between the relevant expert groups, and the predictive nature of the tests used to evaluate such equipment must be improved. To achieve the latter, performance objectives within standards could be made more rigorous and the tests more realistic. Alternatively, the tests could stay as they are and 'correction factors', based on experimental findings and mathematical models, could be employed to adjust the performance observed in tests to that likely to be encountered following an accident. The end result of improving the predictive nature of evaluative tests does not have to be more expensive protective equipment. What it should produce is an accurate estimation of performance during an emergency around which a survival policy can be based with confidence rather than ignorance.

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