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The concept of an 'Integrated Survival System' for protection against the responses associated with immersion in cold water

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Abstract
In this paper the concept of an 'Integrated Survival System' (ISS) is introduced and discussed in relation to the helicopter passenger/crew member, although the principles are equally applicable to many other types of user and circumstance requiring specialized protective clothing.

The fundamental principles behind this concept are first, that the wearer should be given protection against all of the hazardous responses associated with immersion in cold water and secondly, that the individual components which make up the ISS must be compatible and complementary; they may also be interdependent.

INTRODUCTION

The first step in the design of an ISS for any purpose is to identify all of the hazardous responses likely to be encountered by the wearer. With regard to the helicopter passenger, this approach requires the hazardous responses associated with immersion in cold water to be identified and considered. There is, therefore, a clear requirement for an understanding of the relevant basic physiology of cold water immersion and for this knowledge to be employed at an early stage in the design of a system.

HAZARDOUS RESPONSES ASSOCIATED WITH IMMERSION

In recent years the risk associated with cold water has tended to be thought of solely in terms of hypothermia, or a fall in body core temperature. The perception that hypothermia is the major threat faced by individuals who are immersed in cold water has influenced thinking in many areas, including the design of immersion protective clothing and claims for its performance; the tests and standards used to evaluate such clothing and the policies employed to determine which types of protective clothing are acceptable and when they should be worn.[1]

Despite the attention which hypothermia has received, anecdotal,[2] statistical[3,4] and experimental[5] evidence suggests that other responses associated with immersion in cold water can present a significant threat to life. Golden and Hervey[6] have listed four stages of immersion in cold water associated with particular risk, these are:

1. Initial immersion (0–3 min).
2. Short-term immersion (3–15 min).
3. Long-term immersion (30 min+).
4. Post-immersion.

Normally, the possibility of hypothermia does not occur until stage three; before this the immersed individual must survive the initial responses to immersion in cold water. These responses have been given the generic title of the 'cold shock' response, and are summarised in *Figure 1*. In recent years it has become increasingly apparent that the initial cardiovascular and respiratory responses evoked by immersion in cold water are probably the most

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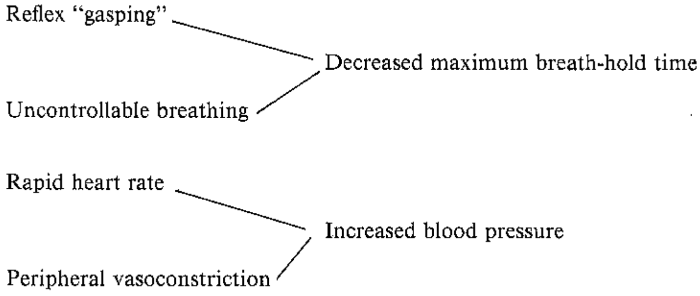

Fig. 1. The initial responses to cold water immersion.

hazardous of all of the responses associated with immersion. In particular, the significant reduction in maximum breath-hold time on immersion is potentially especially hazardous for individuals who may require to perform a breath-hold in order to escape from a submerged boat or craft.

It follows from this that the protective equipment provided for individuals at risk of immersion in cold water, the tests and standards by which such equipment is judged, and the policies for the use of such equipment should reflect all of the hazardous responses associated with immersion in cold water and not just those which result in a fall in core temperature.

Acceptance and implementation of this has profound implications for several areas, including the estimation of survival time; policies for the use of immersion suits; and types of immersion suits recommended.

With regard to survival time, consideration will have to be given to the fact that the cold shock response may incapacitate immersion victims in seconds as opposed to the tens of minutes required by hypothermia. The requirement to wear immersion suits, currently determined by the relationship between water temperature, insulation and time to hypothermia, will also have to take account of the relationship between water temperature and the magnitude of the cold shock response.

Finally, the definition of what constitutes an 'effective' immersion suit, currently based on the protection provided against hypothermia, may alter when the cold shock response is also considered. As this response is evoked by rapid falls in skin temperature, clothing which reduces this rate of fall should attenuate it. It is likely therefore that immersion suits which keep the majority of the surface area of the body dry on immersion ('dry' suits) will have an inherent advantage over suits which, because they do not possess watertight wrist and neck seals, do not achieve this.

Thus, despite the fact that many 'wet' suits have been reported to provide adequate protection against hypothermia, sometimes equivalent or better than that seen with 'dry' suits,[7,8] this may not be the case when considering the protection provided against the cold shock response.[9]

MAJOR COMPONENTS OF A HELICOPTER PASSENGER/CREW ISS

Having identified the responses against which protection is required, the next step in the design of an ISS is the provision of protective equipment, constructed from the most appropriate materials and combined in a way that ensures integration and compatibility. This step may be most efficiently achieved by co-operation between individuals with detailed knowledge of physiology, ergonomics, engineering, textiles and modern manufacturing techniques.

It should be emphasised that only the major components of a helicopter passenger/crew ISS are discussed: other equipment such as gloves, splash-guard, buddy line and so on, should also be present within an ISS. The general point of importance is that such additional items must also conform with the principle of compatibility. Additionally, only protection against cold water will be addressed; there are clearly many other considerations required in the design and evaluation of a helicopter passenger/crew ISS. These include fire protection, comfort in air, durability, snagging avoidance, mobility in air and water.

Protection against cold shock

It is clear that some protection should be provided against the cold shock response, particularly the cold-induced reduction in maximum breath-hold time. Even standard whole-body helicopter passenger/crew immersion 'dry' suits have been shown to enable average maximal breath-hold times in subjects of only approximately 30 seconds during submersion in water at 10°C.[9,10] Indeed, some individuals are able to achieve only 12 second maximum breath-hold times in this clothing.[9]

These results provide the rationale for the inclusion of some form of emergency underwater breathing apparatus (EUBA) in a helicopter passenger/crew ISS. Indeed, an EUBA is considered to be an important, perhaps the most important, component of any helicopter passenger/crew ISS. Protection against the initial respiratory responses to immersion is essential; good protection against hypothermia is clearly pointless unless crew and passengers have a long enough underwater survival time to escape from an inverted or sinking helicopter.

Any EUBA should preferably be simple to use, require little in the way of training and not introduce any additional dangers such as pulmonary over-pressure accidents which may result in pulmonary barotrauma. The demands placed upon any EUBA will be dependent, in large part, upon the immersion suit with which it is worn as part of the ISS.

Another essential component of an ISS is therefore an immersion suit. This should not only attenuate the cold shock response by significantly slowing the rate of fall of skin temperature on immersion in cold water, it should also provide effective anti-hypothermia protection.

Protection against hypothermia

Determining which immersion suits are the most 'effective' is often difficult. Of the different makes of suit currently available it is uninsulated 'dry' suits which have become the most popular; they are thought to provide adequate protection against hypothermia whilst being relatively comfortable to wear in air when compared with either dry suits with inherent insulation or wet suits.

This choice may, however, be in error due to the innocuous nature of many of the laboratory-based evaluations on which it is based. Even in these tests significant levels of water leakage into 'dry' suits has been reported.[9,10,11,12,13] In the real situation leakage is likely to be increased by wind, waves, exercise and an initial period of submersion,[13,14,15] as well as by wearers failing to secure their suits correctly in the emergency situation.[16]

Such leakage will have a deleterious effect on the performance of 'dry' immersion suits without waterproof insulation by reducing the insulation provided by the 'normal' clothing worn beneath the suit.[17,18] Tipton[13] reported a 30% reduction in the performance of an immersion suit as a result of the introduction of a light wind, small waves, periodic surface spraying and a 15-second period of submersion at the start of two otherwise identical laboratory tests of the same uninsulated suit. The deterioration in performance was primarily ascribed to increased water leakage.

Under such circumstances 'dry' suits with inherent insulation which is unaffected by leakage will perform better than those without waterproof insulation. Furthermore, the provision of a suit with inherent insulation also removes the requirement for the often incorrect assumption that the wearer will provide his own adequate insulation.

It is concluded that the immersion suit component of an ISS should demonstrate advanced protection against hypothermia during laboratory tests, to allow for the decrement in performance which will occur in adverse real situations.

Airway protection

Another critical component of an ISS is an effective means of self-righting, keeping the airways clear of the water and maintaining stability in a rough sea-way. These functions may be achieved by a lifejacket. It is essential however, that the lifejacket is integrated with, and complementary to, the other components of the ISS. Many lifejackets have been reported to be unable to function correctly when worn with immersion suits.[19,20]

SUMMARY AND CONCLUSIONS

In this paper the concept of the Integrated Survival System has been introduced and discussed using the example of a helicopter passenger/crew ISS. The major components considered essential in such an ISS are shown in *Figure 2.*

The rationale behind this concept is that the process of providing protective equipment for individuals should start with the identification of all of the hazards to which they are likely to be exposed. These hazards should then be investigated and analysed to determine their nature and the best ways of attenuating the

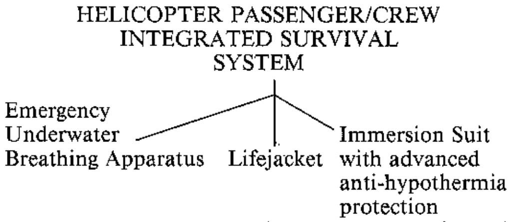

Fig. 2. Recommended major components of a helicopter passenger/crew ISS.

threats associated with them. The information obtained can then be used as a basis for the development of effective protective equipment.

Where more than one hazard exists it is probable that more than one piece of protective equipment will be required. Where this is the case, the different pieces of equipment should be regarded as components of a larger system; these components should be compatible and complementary and may, in some cases, be interdependent. In short, they should constitute an Integrated Survival System.

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