Effectiveness of Limb Immersion as it Relates to Firefighter Stress and Rehab

FIRE FIGHTING IS A PHYSICALLY AND PSYCHOLOGICALLY demanding profession and a potentially hazardous occupation. During the five-year period from 1995 through 1999, an average of 99 firefighters per year lost their lives in the line of duty. The leading cause of death among on-duty firefighters in the United States during the past five years has been heart attack, accounting for 40 percent to 49 percent of the deaths each year.[1]

How Effective is Limb Immersion?

We can provide copies of numerous recent studies that clearly establish that limb immersion is uniquely effective at cooling the core. But perhaps some practical examples will be even more effective:

- Ever put your feet or hands in a pond to cool off on a hot summer day?
- Ever put your forearms under the cool water from the kitchen sink to cool off?

Almost all of us would have to say yes on both counts, so you already know how effective limb immersion is!

Why is Stress Such a Problem for Firefighters?

Fire fighting places considerable strain on the cardiovascular system because of the heavy work firefighters perform and thermal strain. The primary cause of thermal stress, 70% of the total, comes from the internal metabolic heat produced by working muscles. While in the super-heated environment of the fireground, the protective ensemble keeps a firefighter cooler than he would be without gear. Even with that protection level, due to the demanding and physically stressful condition in which a firefighter can find himself, the body's internal heat generation, combined with radiant heat associated with the fire, can increase a firefighter's core body temperature to a dangerous level.

The cardiovascular demands of heavy muscular work and increased body temperature result in competing demands for blood flow to (a) the metabolically active muscles to support heavy muscular work, (b) the skin in response to the themoregulatory demands resulting from muscular work in a hot environment, and (c) vital organs (including the brain and heart) to support life. The cardiovascular demands are exacerbated by excessive fluid loss through profuse sweating and vasodilation of vessels in the skin and muscle.[2]

What has Been Done to Help Firefighters Deal with Stress?

The fire service has been combating heart and the underlying heat stress issues through a number of fireground rehabilitation strategies, such as crew rotation, fluid replacement and cooling that is **passive** (opening up PPE and sitting on the ground in the shade) or **active** (ice packs or vests, air conditioning, misting fans and even cryogenics).

The Problems with These Earlier Rehab Techniques...

The latest research shows that most of these strategies do not work to effectively reduce core temperature. Even more ominously, some of these strategies do reduce skin temperature only and thus "fool" firefighters into thinking they are fit for reassignment, when in fact their core temperatures remain high or continue to climb dangerously. This could encourage a firefighter to dangerously resume work while his core temperature is still dangerously high.

What does the Newest Research Teach?

The research shows that firefighters must **actively** cool and that hand and forearm immersion is the most effective means of reducing core temperature.[3] Combined with rest and hydration, hand and forearm immersion is THE most effective

way for firefighters to mitigate the horrendous impact of stress on their health and safety.

Why is Hand and Forearm Immersion More Effective than the Other Active Cooling Techniques?

The KORE KOOLER REHAB CHAIR relies on direct contact of the skin with a large volume of water through immersion (each arm reservoir can hold several gallons of water). Water has high emissivity, high thermal mass (more than 8lbs to the gallon) and being a fluid, adapts to every inch of the firefighter's hand and forearm for maximum heat transfer. Heat is transferred from the comparatively hotter (than the water) firefighter's arms/hands to the water in the troughs and the cooled blood flows back to the body core picking up additional core heat for subsequent removal. As such, this approach can be used to quickly rehabilitate the individual and minimize the potential for continued core temperature rise that commonly occurs after hard work in insulative clothing or PPE.

In contrast:

- Ice packs are rigid by design and, therefore, do not come into contact with a substantial expanse of skin surface. Their excessive low temperature causes capillaries to constrict which traps heat in the body's core.
- Cooling vests rely on circulating air or liquids through tubes and do not provide the same efficiency as the KORE KOOLER REHAB CHAIR since the heat transfer must occur through the fabric lining and plastic tube walls of the cooling vest before reaching the circulating medium, and the area of body contact is far lower than fluid water provides.
- Air conditioning is effective but less direct (less thermal mass per area of contact) and must overcome the barriers of clothing.
- Misting fans deliver very little thermal cooling to the skin and become even less effective in the high humidity conditions so typical on the fireground.
- Cryogenics has the same limitations as cooling vests. Additionally, the thermal gradient is often so high that skin cooling can constrict the capillaries before effective blood stream cooling can occur.

Perhaps even more importantly, unlike the other active stress mitigation technologies (ice packs or vests, air conditioning, misting fans and even cryogenics), hand and forearm immersion is both portable and affordable. For the first time, we have an effective, easy-to-use tool that can help mitigate the firefighter stress problem at very low cost.

How Effective is Limb Immersion?

Studies have been conducted that verify the unrivaled core cooling effectiveness of limb immersion in readily available (not chilled) water.[4] Specifically, studies have shown core temperature decreases of 1.3 to 2.9° F (0.7 to 1.6° C) when hands and arms have been immersed in non-chilled water for 10-20 minutes following hard work activity for individuals wearing protective clothing.[5,6] This is a huge temperature change since the difference between normal body temperature of 98.6° F (54.78° C) and threshold heat stress for medically selected and acclimatized personnel of 101.3° F (38.5° C)[7] is a difference of only 2.7° F (1.5° C). For purposes of these studies, unchilled water is defined as having a temperature of between 50-86° F (10-30° C), which is the range of water temperature normally anticipated from a tap, hose line, tanker, etc.

Contact us for greater detail on rehab studies and/or draft use protocols.

1 NFPA's Survey of Fire Departments for U.S. Fire Experience (2001), NFPA Fire Analysis and Research Division, Quincy, MA 02269
2 D.L. Smith, PH.D, T.S. Manning, M.S., and Petruzzelo. PH.D. "Effects Of Live Fire Training On Recruits"
3 Tom M. McLellan, PHD, "Current Fire Fighter Occupational Medicine Issues, Approaches for Fire Fighter Rehabilitation," Speaker's Abstract from the International Association of Fire Fighters' Redmond Symposium of October 2003
4 Livingston, S.D, R. W. Nolan and S. W. Cattroll, "Heat Loss Caused by Immersing the Hands in Water", Aviation, Space and Environmental Medicine, December 1989, pp. 1166-1171
5 House, J.R., "Extremity Cooling as a Method for Reducing Heat Strain," Journal of Defense Science, Vol. 3, No. 1 1998
6 House, J.R., C. Holmes, and A. J. Allsopp, "Prevention of Heat Strain by Immersing the Hands and Forearms in Water," Journal of Royal Naval Medical Service, Vol 83, No. 1, 1997, pp. 26-30
7 American Industrial Hygiene Association Guidelines

Rehab Research and Standards

Heat Stress and Cooling Technologies

NFPA 1584 addresses rehab techniques, but was written in 2003 before the latest research on the effectiveness of limb and forearm immersion was available. We understand fire fighting and other forms of emergency response are physically and psychologically demanding professions. During the five-year period from 1995 to 1999, an average of 99 firefighters per year lost their lives in the line of duty. The leading cause of death among on-duty firefighters in the United States during the past five years has been heart attack, accounting for 40 percent to 49 percent of the deaths each year.[1]

Definition and Types of Heat Stress

Heat stress is an increase in human body temperature and metabolism caused by physical exertion and/or a heated environment which can lead to exhaustion, mental confusion, disorientation, dehydration, loss of consciousness, heart attack, stroke and other fatal illnesses. Exerting yourself while performing strenuous tasks in the heated environment of an emergency scene or in warm and/or humid weather may also increase your heat stress.

Heat stress results from an imbalance between heat gain and heat loss, such that more heat stays in the body faster than can be dissipated through the different heat loss mechanisms, such as sweating (evaporative heat loss) and conduction. With the inability to relieve itself of this excess heat, the body's core temperature rises. Heat stress can also be manifested by an imbalance of electrolytes and a lack of proper hydration in response to high heat and heavy workloads. The effects of elevated core temperature and prolonged heat exposure include:

- Heat rash
- Heat cramps
- Heat exhaustion
- Heat stroke
- Heat syncope (fainting)
- Transient heat fatigue

The table on the next page provides the signs and symptoms of heat stress.

Causes and Factors for Heat Stress

Heat stress is caused by:

- **Prolonged exposure to hot environments –** When environmental temperatures approach normal skin temperature (approximately 91.5° F or 33° C), cooling the body becomes more difficult. If the air temperature is as warm or warmer than the skin, heat transfer away from the body through conductive and convective means decreases to the point where it is reversed; thus, heat is gained by the body. In these circumstances, the heart continues to pump blood to the body surface where the sweat glands empty electrolytes and water onto the surface of the skin and evaporation becomes the only effective method of maintaining body temperature. However, under conditions of high humidity, even the evaporative mechanisms decrease, and the body's efforts to maintain an acceptable body temperature are significantly impaired. With a large quantity of blood going to the external surface of the body, little remains for the active muscles, the brain, and the internal organs, leading to declines in strength with fatigue occurring quickly.
- **Sustained physical or high levels of work activity –** Increased or strenuous physical activity provides more and more metabolic heat. The body must get rid of this heat in order to prevent an increase in core temperature.
- **Wearing of insulated protective clothing –** Protective clothing inhibits the transfer of heat between the body and the surrounding environment. Therefore, in jobs where the air temperature is lower than skin temperature, wearing clothing reduces the body's ability to lose heat into the air. When air temperature is higher than skin temperature, clothing helps to prevent the transfer of heat from the air to the body. However, this advantage may be nullified if the clothes interfere with the evaporation of sweat. For example, even though firefighter protective clothing is considered breathable, the clothing does not permit sufficient moisture vapor transport away from the body, and the environment between the body and the clothing quickly becomes saturated with moisture, affecting the body's heat loss through evaporation of sweat. In addition, the inability for clothing layers to absorb sweat can also create discomfort and lead to stress. Protective clothing further adds weight and bulk that causes further stress on the body and the expenditure of additional energy which in turn generates greater metabolic heat.
- **Individual susceptibilities –** Certainly individuals who have a better level of physical fitness are less likely to experience heat stress than individuals who are relatively out of shape or in poor physical health. Acclimatization to hot environments is necessary to allow individuals' bodies to adapt to high heat. Acclimatization can take several days to weeks depending on the level of heat exposure that occurs relative to the normal environment that workers may be used to. The aging process results in a more sluggish response of the sweat glands and consequently a less effective control of body temperature. Older persons also experience increased levels of skin blood flow with exposure to heat creating additional thermoregulatory strain. Dehydration and loss of electrolytes, as previously pointed out, put the individual at increased risk for heat stress. Alcohol interferes with the body's hydration process while several drugs have different effects on the body's ability to respond to heat.

[1] NFPA's Survey of Fire Departments for U.S. Fire Experience (2001), NFPA Fire Analysis and Research Division, Quincy, MA 02269

Fire fighting and other emergency response activity places considerable strain on the cardiovascular system because of the heavy work performed by emergency personnel (including carrying the weight of the personal protective equipment) and thermal strain. Thermal strain results from several factors, including (a) the metabolic heat produced by working muscles; (b) the heavy, insulative, only semi-permeable protective gear, which adds to the metabolic work that must be done and traps the metabolic heat next to the body; and, in some cases, (c) the radiant heat associated with the fire.

The cardiovascular demands of heavy muscular work and increased body temperature result in competing demands for blood flow to (a) the metabolically active muscles to support heavy muscular work, (b) the skin in response to the thermoregulatory demands resulting from muscular work in a hot environment, and (c) vital organs (including the brain and heart) to support life. The cardiovascular demands are made worse by excessive fluid loss through profuse sweating and dilation of blood vessels in the skin and muscle.[2]

Approaches to Heat Stress Relief

The prevention or alleviation of heat stress is based on affecting each of the factors that contribute to its onset:

- Altering the environment
- Modifying the work to be performed
- Lessening individual firefighter susceptibility
- Changing the protective clothing
- Using auxiliary cooling

Given all of the different approaches for heat stress, there are still activities and circumstances for which other approaches or combinations of these approaches must be employed. For example, in structural fire fighting, the firefighters cannot choose their environment (which is undoubtedly hot), modify their task (except by adding manpower to fire fighting operations), or provide any further changes in the protective ensemble without sacrificing protection. In such situations, principles from each approach described above must be

[2] D.L. Smith, PhD, T.S. Manning, M.S., and Petruzzelo, PhD "Effects Of Live Fire Training On Recruits," Fire Engineering, September 2001, pp. 79-81.

Signs and Symptoms of Heat Stress

Heat Rash – occurs in hot, humid environments where sweat is not easily removed from the surface of the skin by evaporation and the skin remains wet most of the time. The sweat ducts become plugged; signs and symptoms include:

- Skin redness and raised bumps on the skin

Heat Cramps – result from heavy sweating with inadequate electrolyte replacement (calcium, potassium and sodium chloride), imbalance during heat stress and increased sweating. Signs and symptoms include:

- Muscle cramps
- Pain in the hands, feet, and abdomen

Heat Exhaustion – caused by increased stress on various body organs including inadequate blood circulation due to cardiovascular insufficiency or loss of excessive amounts of fluids, electrolytes, or both, through increased sweating. Signs and symptoms include:

- Pale, cool, moist skin
- Heavy sweating
- Thirst
- Dizziness
- Nausea
- Dry mouth and tongue (cotton-mouth)
- Elevated skin and core temperature
- Fainting

Heat Syncope (Fainting) – occurs when there is a sudden lack of blood flow to the brain. During heat stress conditions, the brain does not receive enough blood, and hence required oxygen, because of mechanisms initiated to reduce increased body heat. With vasodilated blood vessels in the skin and in the lower part of the body, blood flow is increased, resulting in 'blood pooling' in the extremities rather than being returned to the heart to be pumped to the lungs and to the brain. Signs and symptoms include:

- General weakness
- Low blood pressure
- Paleness
- Fatigue
- Blurred vision
- Elevated skin and core temperatures

Heat Stroke – the most serious form of heat stress. It occurs when the body's temperature regulatory system fails and sweating becomes inadequate. The body's only effective means of removing excess heat is compromised with little warning to the victim that a crisis stage has been reached. Unless the victim receives quick and appropriate treatment, death can occur. Signs and symptoms include:

- Red or blotchy, hot, usually dry skin
- Nausea
- Strong, rapid pulse
- Lack of or reduced perspiration
- Dizziness and confusion
- Coma
- Body temperature is usually 105° F (41° C) or higher

Transient Heat Fatigue – refers to the temporary state of discomfort and mental or psychological strain arising from prolonged heat exposure. Signs and symptoms include:

- A decline in task performance, coordination, alertness, and vigilance.

used. The use of ***rehabilitation programs*** is in essence a combination of the first four methods. Rehabilitation is post work or rest period management of the individual's environment, activity, condition, and clothing to limit the effects of heat accumulation from work in hot environments.

The fire service has been combating heat stress issues through a number of fireground rehabilitation strategies, such as crew rotation, fluid replacement and cooling that is **passive** (e.g., opening up PPE and sitting on the ground in the shade) or **active** (ice packs or vests, air conditioning, misting fans and even cryogenics).

Some of the auxiliary cooling technologies are not practical for many applications because of the additional hazards (other than heat stress) faced by emergency responders. Furthermore, many of these technologies further encumber workers, which in turn can diminish the additional cooling effect that is achieved by the device. A number of studies have involved the evaluation of different cooling systems, particularly those for use with military permeable and impermeable chemical agent protective gear.

The latest research shows that most of these strategies do not work to effectively reduce core temperature. Moreover, some of these strategies reduce skin temperature and thus "fool" firefighters into thinking they are fit for reassignment, when in fact their core temperatures remain high or continue to climb dangerously.

Studies aimed at alternative means of cooling have shown the beneficial results of limb immersion combined with other rehabilitation techniques. The British Navy investigated the use of limb immersion for cooling sailors during the Falklands Campaign. In their studies, hand and/or foot immersion in cool water was examined as a means to cool shipboard personnel. Cooling through hand or foot immersion occurs through heat exchange in blood vessel branchings near the skin that remain open and dilated when core temperature is elevated. In successive studies, the Institute of Naval Medicine in the United Kingdom was able to show that by cooling the limbs of test subjects, the rate of core temperature rise was halted.[3, 4] These studies involved the examination of forearm immersion in water ranging from 49.5° F (10° C) to 85.5° F (30° C) for test subjects that had exercised until their core temperature rose to 101° F (38.5° C) while wearing fire fighting clothing. Additional studies compared limb immersion with conventional cooling vests with limb immersion providing more effective cooling than ice vests.

More recently, work by Defense Research and Development of Canada examined the efficacy of passive cooling compared with active cooling and hydration strategies.[5] The first phase of this research showed that a passive rehabilitation approach with rest periods between 30-minute work periods was unable to provide effective cooling, and with increasing environmental temperature, firefighter tolerance time decreased. As in other studies, the research showed that heart rate recovery and subjective feelings of comfort

[3] J. R. House, C. Holmes, and A. J. Allsopp, (1997). "Prevention of Heat Strain by Immersing the Hands and Forearms in Water," J. Royal Naval Medical Service, 83(1), pp. 26-30.

[4] S. D. Livingstone, R. W. Nolan and S. W. Cattroll, (1997). "Heat Loss Caused by Immersing the Hands in Water," Aviation, Space and Environmental Medicine, December, pp. 1166-1171.

[5] Presented at 2003 IAFF John P. Redmond Foundation Symposium, October 2003.

Comparison of Earlier Auxiliary Cooling Technologies (Before Limb and Forearm Immersion was Identified as the Most Effective Process)

Type of Cooling System	Advantages	Disadvantages
Water-cooled Garments	Cooling rate can be controllable	Bulky and heavy; Limited service life; Requires replenishment; Hard to integrate with many forms of clothing
Air Cooling Systems	Simple; Some provide control of cooling rate	Noisy; Mobility is severely restricted; Requires source of compressed air
Ice Packet Vests	Simple; Inexpensive	Can add significant bulk and weight; No control over cooling rate; May cause initially vasoconstriction and diminish cooling effect
Phase Change Material Clothing	Simple; Can conform to body in lightweight, low bulk designs	No control over cooling rate; System may have limited lifetime under high heat conditions; Recharging clothing can be difficult
Wetted Overgarments	Simple	No control over cooling rate; Can add bulk and weight; Does not provided evaporative cooling inside encapsulating clothing or under high humidity conditions

were not reliable indicators of the heat strain being experienced by the firefighter.

A second phase of the research compared rehabilitation practices using one of three different techniques:

- Passive cooling only (removal of coat, helmet, SCBA, and gloves)
- Removal of coat, helmet, SCBA, and gloves with water misting
- Removal of coat, helmet, SCBA, and gloves with forearm cooling

Firefighter test subjects engaged in a 50-minute period of light work (including one bottle change) followed by a 30-minute rest period where one of the rehabilitation techniques was used. Test subject core temperature was measured as a determinant of the level of stress in each firefighter. The results from this research are shown in the graph below. These results demonstrated that with passive cooling only, firefighters were not able to complete a second work period. ***When active cooling was applied, the technique of limb immersion permitted firefighters to sustain longer work periods with a limited rise of core temperature.***

Fire Service Standard and Practices

In the fire service industry, specific standards and publications have addressed rehabilitation practices:

- In 1992, the U.S. Fire Administration published Emergency Incident Rehabilitation (FA-114). This publication establishes recommendations for a fire department or other emergency organization standard operating procedure for rehabilitation and provides guidelines for rehabilitation responsibilities, hydration, nourishment, rest, recovery, medical evaluations, and accountability. This publication has been updated by the IAFF and will be published by the end of 2007.
- NFPA 1500, 2007 edition, includes requirements for fire departments to address rehabilitation during emergency operations (Section 8.9). These requirements essentially direct the department to provide on-scene rehabilitation of firefighters during emergency operations, permit communications of rehabilitation/ rest needs to supervisors, and provide wildland firefighters with a minimum of 2 liters of water.
- NFPA 1584, 2003 edition, is a new Recommended Practice on Rehabilitation of Members Operating at Incident Scene Operations and Training Exercises. Important provisions of this Standard require fire departments to:
  - Develop standard operating procedures for rehabilitation following operations;
  - Establish areas of rehabilitation with specific characteristics (e.g., in the shade, away from any hazards, with access to medical treatment);
  - Specify the role of emergency medical service personnel;
  - Undertake a rehabilitation process that includes (1) removal of all protective clothing, (2) fluid replenishment, (3) use of a shaded or misted area for cool-down, (4) use of an air-conditioned space for extended rehabilitation, and (5) medical evaluation and treatment for heat emergencies;
  - Provide medical monitoring, including member subjective ratings, heart rate, blood pressure, and temperature;
  - Follow specific work-to-rest ratios based on cylinder use; and
  - Document heat stress incidents.

The Superiority of Limb and Forearm Immersion