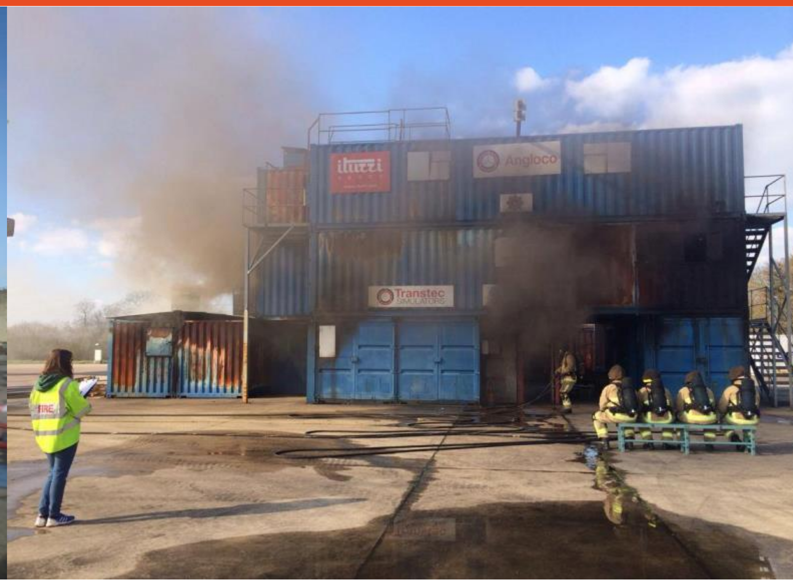
# FIREFIGHTER HEAT EXPOSURE: Considerations for Preparation, Recovery and Heat Illnesses

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## GLOSSARY OF TERMS

| | |
|---|---|
| **Acute** | **i**mmediate |
| **Cardiac troponin** | blood marker of heart muscle damage |
| **Euhydration** | normal state of body water content |
| **Heat dissipation** | type of heat transfer, process of becoming cooler |
| **Homeostasis** | a stable equilibrium maintained by physiological processes |
| **Physiological strain** | characteristic of or appropriate to an organisms healthy or normal functioning |
| **Stroke volume** | volume of blood pumped from the left ventricle per beat |
| **Tc** | core temperature (°C) |
| **Thermoreceptors** | specialised nerve cells that are able to detect differences in temperature |
| **Thermoregulation** | ability of an organism to keep its body temperature within certain boundaries even when surrounding temperatures change |

## INTRODUCTION

Occupational health is of great importance to minimise sick days taken by employees, and to maximise individuals' wellness and ability to complete tasks (Sparks et al. 2001). Maintenance of workers health is of paramount significance when the occupation involves dangerous and extreme environments, due to the increased level of risk experienced by each employee (McDonough et al. 2015). Fire service instructors (FSI) are frequently exposed to high temperatures and hazardous situations when teaching trainee firefighters (FF) (Watt et al, 2016). These live fire situations put them at risk of exertional heat illnesses and cardiovascular events (Casa et al. 2015; Fahy et al. 2015). Meanwhile, recruits with no previous fire exposure may be at greatest risk due to their unknown heat tolerance and lack of prior acclimatisation. To help reduce the risk of heat illness or long term health issues, there are methods available to help prepare for and recover from hot wears.

While this pack is not a policy document or a guidance report, the content should be used to educate fire personnel about methods to help minimise the health risks of live fire exposure for their own personal welfare. The pack covers thermoregulation, physiology of firefighting, heat illnesses, treatment, preparation and recovery from hot wearing. The content and recommendations are based on research and evidence based practices published worldwide.

The content of this pack includes:

- a research based information pack including recommendations, key points and questions to test knowledge.
- a voice over film presentation of the fundamentals of thermoregulation, heat illness, cooling and hydration methods.
- a powerpoint presentation of the fundamentals of thermoregulation, heat illness, cooling and hydration methods with notes deliverable by instructors.
- a voice over film on scientific considerations of thermoregulation, heat illness, risk factors and treatment methods.
- a powerpoint presentation on scientific considerations of thermoregulation, heat illness, risk factors and treatment methods with notes deliverable by instructors.
- a short film on heat illness, risk factors and treatments.
- a short film on hydration, cooling methods.
- a short film on the demonstration of the 'TACO roll' whole body cooling.

## THERMOREGULATION

Thermoregulation maintains the homeostasis of the body, keeping core temperature ($T_c$) at ~37°C, which varies by ±0.8°C throughout the day (Havenith 2002). $T_c$ natural daily fluctuation reaches a peak plateau from 14:00 to 20:00 hrs, and a minimum just after the mid-point of sleep, commonly around 05:00 hrs (Waterhouse et al. 2005). Increased ambient temperature can affect homeostasis, with changes superimposed upon daily alterations (Waterhouse et al. 2005).

Central thermoreceptors, in the brain's hypothalamus, and peripheral thermoreceptors, in the skin, detect changes in temperature and, via neurons, provide information to the hypothalamus (Illigens & Gibbons 2009). Detection of an increased temperature causes heat loss mechanisms to be instigated, including vasodilation of peripheral blood vessels and an increased sweat response. Vasodilation of blood vessels near the skin increases skin blood flow, consequently increasing convective heat transfer from the core to the periphery (Charkoudian, 2016). Sweating enables evaporative heat loss from the skin, consequently cooling the skin and increasing heat transfer from the surface of the skin to the environment, therefore dissipating large amounts of heat (Wendt et al. 2007). During exercise the evaporation of sweat accounts for 80% of heat loss. Figure 1. gives a schematic overview of the thermoregulation process.

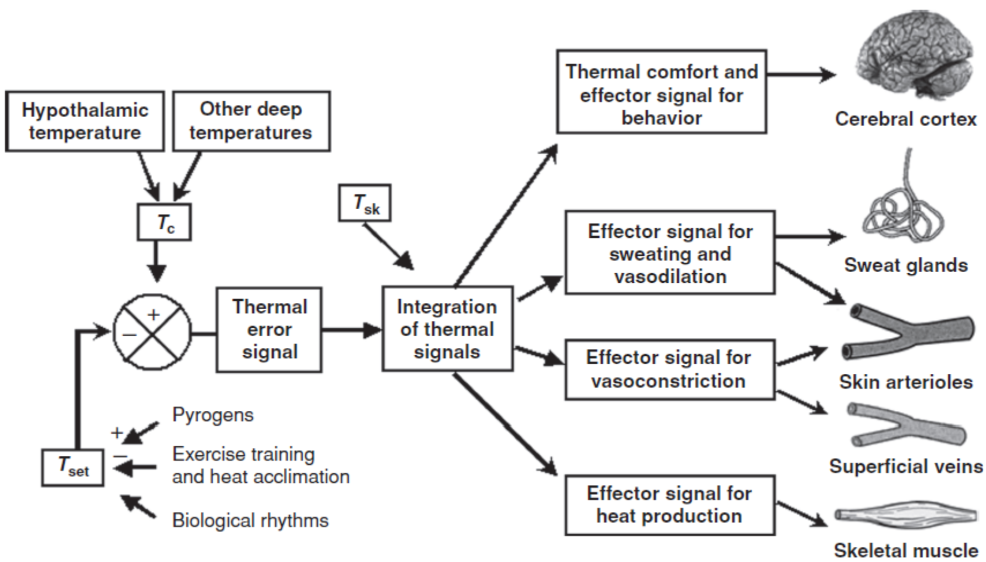


***Figure 0.*** *Schematic of thermoregulatory control system, from Sawka & Young (2006).*

In addition to external heat gain, heat is also produced during the conversion of metabolic energy into mechanical and thermal energy in all body cells. Due to the inefficiency of this process energy released by muscle contractions is 30-70% thermal (Krustrup et al. 2001; Bangsbo et al. 2001; González-Alonso 2012). Metabolic heat production therefore also stimulates heat loss mechanisms (Brotherhood 2008).

To maintain $T_c$ during external and internal thermal gain the body must be able to get rid of sufficient heat. In an attempt to dissipate heat, blood flow is redirected to the skin, competing with muscle blood flow requirements. This causes heart rate to increase (Eglin 2007; Sawka et al. 2011; Périard et al. 2016). The balance to prevent heat storage can be represented by the heat exchange equation:

$$\pm S = M - (\pm W) - E \pm K \pm C \pm R \left(\frac{W}{m^2}\right)$$

where: S is heat storage, M is metabolism, W is positive or negative work, E is evaporation, K is conduction, C is convection and R is radiation (Gavin 2003). To prevent heat storage the body mainly relies on sweat loss to cool the body via evaporation.

Heat can be gained from the environment via:

**Radiation**: during fire exposure the radiation of electromagnetic waves causes heat gain.

**Evaporation:** In a hot environment heat loss is impaired, due to a decrease in the thermal and water pressure gradients between the body and the environment and the wearing of PPE.

**Conduction:** conduction of heat via contact points with surrounding surfaces will cause heat gain, due to the surrounding surface temperatures.

**Convection:** the movement of hot air past firefighters will also add to the external thermal load.

## Key Points

- Body temperature fluctuates 0.8°C throughout the day.
- Humans are naturally hotter in the afternoon compared to the morning due to circadian rhythm.
- Sweating accounts for 80% of heat loss during exercise.

## Recommendations

- Check your core temperature before heat exposure, especially in the afternoon if you have previously completed a heat exposure in the morning

## Check your knowledge

1. What is a normal resting core temperature?
2. What time of day is you temperature likely to be highest?
3. How can heat be gained from the environment?
4. What physiological mechanism has the greatest effect on thermoregulation?

## THERMAL CONSEQUENCES OF PPE

Wearing PPE decreases an individual's ability to dissipate heat, as there is limited water vapour permeability across the clothing layers (Cheung et al. 2000). In addition, the further the distance away from the skin that moisture evaporation occurs the greater the reduction in the cooling efficiency of evaporation (Havenith et al. 2013). The weight of the PPE and BA also increases the work load experienced, therefore increasing heat production and cardiovascular strain (Huck 1988; Holmér et al. 2006).

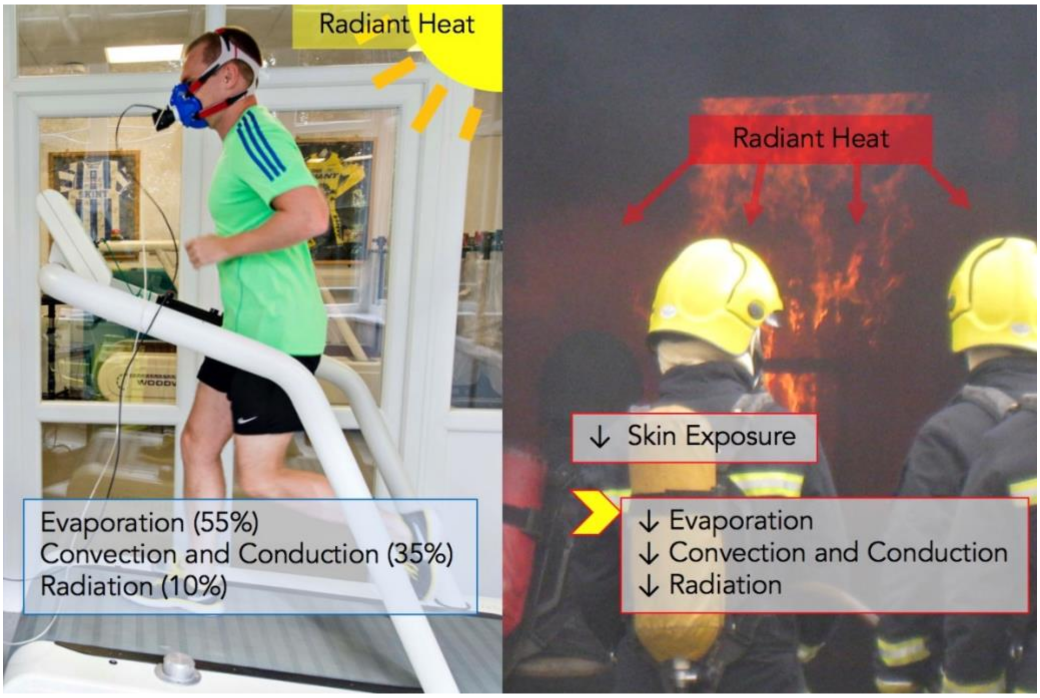


***Figure 2.*** *heat balance when exercising normally compared to when wearing PPE.*

During stepping, walking, and obstacle exercises in ambient temperatures metabolic rate increased by an average of 14.7% when wearing 6.66kg of PPE compared to wearing tracksuit bottoms and a t-shirt (Dorman & Havenith 2009). Carrying BA also increases $O_2$ consumption, with an 11kg BA resulting in a $\dot{V}O_2$ of 28.1 ± 3.3 $ml.kg^{-1}.min^{-1}$ compared to 21.6 ± 2.5 $ml.kg^{-1}.min^{-1}$ without a BA at the end of exhaustive exercise (Bakri et al. 2012). It is suggested that for each kg of additional weight metabolic rate increases by 2.7% (Dorman & Havenith 2009). Despite this, weight alone is not the only cause of increased metabolic rate, with differences in material, number of layers, and BA harness design also having an impact (Dorman & Havenith 2009; Bakri et al. 2012). This is evidenced by Taylor et al (2012) who noted that whilst the heaviest item worn by firefighters is their BA, during walking both the BA (11.30 kg) and protective clothing (without boots and helmet) (4.72 kg) contributed 9% to the metabolic rate increase.

Overall, during a fire exposure the evaporative heat loss required to maintain a thermal steady state exceeds the maximal evaporative capacity of the environment (Montain et al. 1994; Cheung et al. 2000), as a consequence of the PPE, BA, physical activity, and environmental conditions. This is referred to as an uncompensable heat stress situation, whereby the body continually stores heat, consequently causing a rise in Tc (Cheung et al. 2000).

## Key Points

- Wearing PPE impairs the ability to dissipate augmented levels of stored heat whilst performing occupational duties in heat stress.
- If this stored heat is not evaporated, increasing body temperature will continually rise

## Recommendations

- Ensure PPE is adequately fitted, without unnecessary additional weight and correct undergarments are worn, to reduce physiological strain and inflammatory responses.

## Check your knowledge

1. How does PPE increase physiological strain?
2. How does the hot environmental conditions increase physiological strain?
3. What is meant by uncompensable conditions?

## PHYSIOLOGICAL CONSEQUENCES OF SEVERE HEAT EXPOSURE

A fire exposure can increases Tc by 0.6 - 3.2°C, with average maximum temperatures reaching 40.1°C, as reported in Table 1.

The increased demand for blood at the skin, for heat dissipation, and at the muscles, to perform physical activity, combined with dehydration due to sweating leads to decreased plasma volume in the blood (Charkoudian 2016). The combination of a 1°C rise in Tre with 4% dehydration can lead to a 20 ± 1% reduction in stroke volume and consequently a 13± 2% reduction in cardiac output (González-Alonso et al. 1997). The vasodilation of peripheral blood vessels also decreases the venous return of blood, adding to the decrease in stroke volume. The reduced stroke volume and cardiac output challenges the body to maintain blood pressure, meet muscle and skin demands, and also ensure the supply to vital organs is adequate (González-Alonso et al. 2008). Overall, the cardiovascular system is put under a high level of strain during fire exposures, with maximum heart rates recorded of 120-194b.min$^{-1}$, as displayed in Table1.

The wide variety of Tc and HR responses is a consequence of the range of environmental temperatures experienced and different tasks performed. Instructors monitored during two live house fire exercises, have displayed average heart rates of 131±18 b.min$^{-1}$ and 121±20 b.min$^{-1}$, with maximum HR obtained equating to 87±5% and 77±11% of predicted HR maximum (Eglin & Tipton 2005). Previous monitoring of firefighters in a high rise fire scenario has resulted in 37.5% of exercises being terminated due to Tc exceeding the safety limit of 39.5ºC, with a further 40% terminated by FF or safety officers due to concern for safety (Optimal Performance Limited 2004).

***Table 1**: Normal values for rest and end of a live fire.*

| Variable | Rest | Firefighting |
|---|---|---|
| Heart Rate (bts/min) | 65 | 185 |
| Core Temperature (°C) | 37.2 | 38.8 |
| Stroke Volume (ml/bt) | 80 | 130 |
| Cardiac Output (L/min) | 5 | 25 |
| Oxygen Consumption (ml/kg/min) | 3.5 | 43 |

***Table 2.*** *Summary of studies reporting mean core temperature and HR during fire-fighting tasks. * denotes ambient temperature is estimated from (Smith et al. 2001a) and Smith & Petruzzello (1998). Table 2 adapted from Eglin (2007).*

| Duration (min x rep) | Ambient Temperature (°C) | Max/end Tc (°C) | Change in Tc (°C) | HR Max ($b.min^{-1}$) | Reference |
|---|---|---|---|---|---|
| 3 x 6 | 54-79 | 37.3 | 1.5 | 194 | Smith & Petruzzello (1998) |
| 3 x 7 | 47-61 | 36.9 | 0.8 | 189 | Smith et al. (2001a) |
| 33 | 66 | 38.5 | 1.0 | 138 | Eglin et al. (2004) |
| 12-92 | 48 | 38.0 | 0.4 | 131 | Eglin & Tipton (2005) |
| 18 | 71-82 | ___ | 0.72 | 167 | Smith et al. (2011) |
| 20 | ___ | 38.2 | 0.84 | 175 | Colburn et al. (2011) |
| 12 | 178-309 | 38.0 | 0.7 | 152 | Burgess et al (2012) |
| 180 (15-30 x 4) | ___ | 38.7 | 1.8 | 188 | Horn et al. (2013) |
| 20 x 2 | 105 | 38.9 | 1.4 | ___ | Walker et al. (2014) |
| 20 x 2 | 100 | 38.7 | 1.4 | 91% HRmax | Walker et al. (2015) |
| 14 | 85-135 | 38.7 | 1.4 | 188.0 | Horn et al. (2015) |
| 37 | 174 | 38.1 | 0.8 | 120 | Watt et al. (2016) |
| 11-28 | 54-744 | 37.91-38.88 | 0.93 – 1.77 | 178-188 | Horn et al (2017) |

Activity may be terminated early by an individual if they reach a critical Tc (González-Alonso et al. 1999; Walters et al. 2000). González-Alonso et al (1999) stated that regardless of initial Tc all cycling exercises in 40°C, 19% RH were terminated at 40.1 – 40.2ºC. Individuals with only a moderate level of fitness ($VO_2$ maximum 40 – 50 $ml.kg^{-1}.min^{-1}$ may have a lower critical temperature (~39 ºC)(Cheung & McLellan 1998; Selkirk et al. 2001) due to a reduction in thermal tolerance and differences in the efficiency of blood flow distribution (Cheung & Sleivert 2004).

During an uncompensable heat stress situation, caused by wearing PPE, firefighters time to exercise termination, whilst walking on a treadmill, was significantly reduced in 35ºC compared to 25ºC, at different exercise intensities: 67.3±3.0 min vs. 134.0±9.3 min, respectively. (Selkirk & McLellan 2004). Exercise termination coincided with Tc elevation of 1-1.4 ºC above baseline, with 63% of terminations due to a Tc of 39.0 ºC, similar to the critical temperature for moderately training individuals (FF $VO_{2max}$: 51.3 ± 1.0). The maximum environmental temperature used was lower than that experienced during a fire exposure, and therefore may underestimate the effect that heat has on Tc and task completion.

## Key Points

- Firefighting tasks can increase core temperature by 0.6-3.2°C.
- Firefighting tasks can increase heart rate up to >90% of maximum.

## Check your knowledge

1. What core temperature do some fire service use as a training limit?
2. What are the other factors which impair firefighter abilities in extreme heat stress?
3. What can decrease a firefighter’s heat tolerance?

## RISK FACTORS FOR HEAT ILLNESS

With no two firefighters presenting the same personal characteristics, it is unsurprising individual responses to environmental stress and occupational tasks are observed. Therefore, it is vital to understand how each firefighter responds during and after exercise-heat stress, as many contributing risk factors can increase the physiological response to fire exposures and the susceptibility to heat related illness, see Figure 3.

One risk factor is a firefighter's aerobic capacity. Higher trained individuals present heat acclimated characteristics (e.g. lower resting core temperature and larger sweat rate) (Aoyagi et al. 1997), allowing firefighters to tolerate heat stress better and extend their time during occupational tasks. A larger body size is another risk factor, as it results in a lower body surface area to body mass ratio, as found in those with higher adiposity (e.g. fat mass), which contributes to a faster rise in core temperature (Selkirk et al. 2001). Underlying illnesses can also increase the risk of exertional heat illness, especially those that cause elevated resting $T_{c}$. Age is also a risk factor, as it is typically combined with a lower $\dot{V}O_{2max}$ and potential underlying illnesses, but also presents impairments in cardiovascular function and sweating responses (Kenny et al. 2010).

Other factors related to an increased risk to firefighter's health status include: skin graft/burnt skin (Ganio et al. 2015), previous episodes of heat related illness (Armstrong et al. 1989), sleep deprivation (Coris et al. 2004; Relf et al. 2018), alcohol intake and tattooed skin (Luetkemeier et al. 2017), which have shown to impair thermoregulation and sweating capacity, thus placing a larger burden on the firefighter.

Prescribed medication including: diuretics, hypertensive medications, beta-blockers, antipsychotics, anticholinergics, antidepressants, anticonvulsants, migraine drugs (e.g. Pizotifene and Triptanes) (Minard 1980; Hajat et al. 2010) can increase risk of heat illness because of the effect on reduced cardiac output and thirst sensation, which can impair thermoregulation, sweating and the perception/feeling of heat stress. Some recreational drugs (e.g. cocaine, amphetamines) may also impact thermoregulation.

Other factors include heat acclimation history (Horowitz 2014) and geographical residence (e.g. natural heat acclimatisation) (Sawka et al. 2011), which are likely to provide benefits in physiological responses to heat stress as similarly shown following heat acclimation (Sawka et al., 2011).

Knowing and understanding how each firefighter responds, either negatively or with little change, can help personalise preparation and recovery strategies for future exposures which may help alleviate the increased physiological strain.

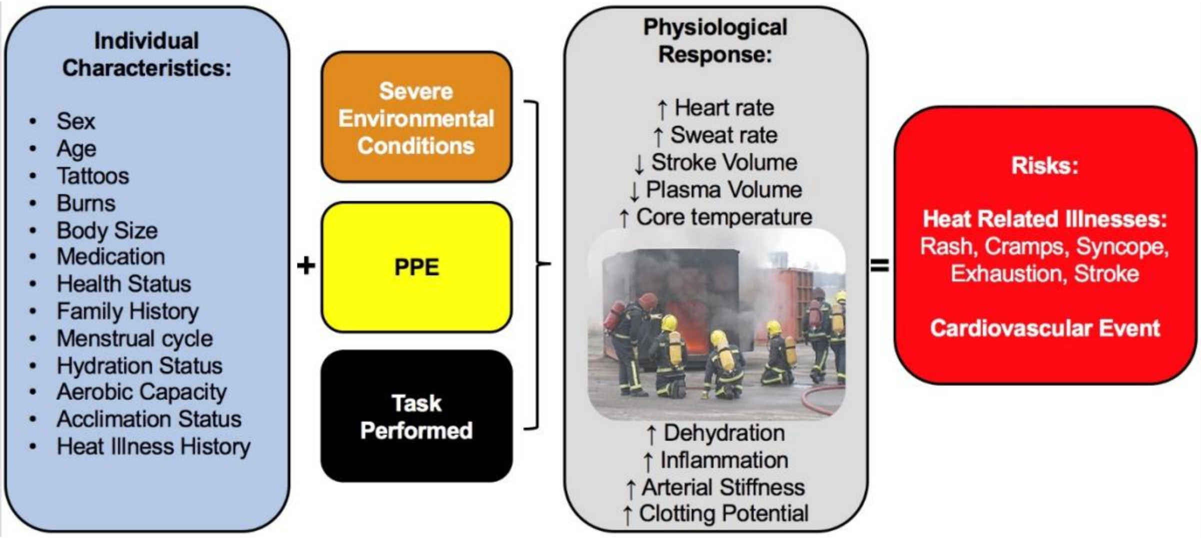


***Figure 3.*** *Individual characteristics and physiological responses to live fire exposure.*

**Sex Differences**

Sex is a predisposing factor for heat related illness with research indicating that females are less tolerant of exposure to hot environments than males. It is acknowledged that females are more challenged under heat stress compared to males and this is particularly due to alterations in sweat response (Gagnon & Kenny 2011). Sweating starts later in females, as a higher $T_c$ and skin temperature is needed to stimulate sweating (Bar-Or 1998). In addition, female body composition is different to males, with females typically having a greater body fat percentage than males of a similar body mass. Females also have a reduced amount of sweat glands activated and the distribution of sweat is also different between sexes.

Females experience fluctuations in hormonal releases until menopause and these cause regular cyclic changes in a number of physiological parameters which may alter heat tolerance. The menstrual cycle consists of: the follicular phase (days 0-16), ovulation at days 12-16 followed by the luteal phase (days 16-28). During the luteal phase progesterone concentrations are elevated (~10 ng.mL$^{-1}$) increasing resting core temperature by ~0.3-0.6°C, resting heart rate by 5b.min$^{-1}$, onset threshold for vasodilation by 0.2-0.3°C and sweating threshold by 0.3°C (Marsh & Jenkins 2002). The luteal phase also presents an increased respiratory demand with elevated oxygen consumption results reported at differing exercise intensities (Marsha and Jenkins, 2002). These increases in thermoregulatory and cardiorespiratory function during the luteal phase of the cycle cause an increased risk for females when under heat stress.

## HEAT ILLNESS SYMPTOMS AND TREATMENT

### Key Points

- Physiological responses to fire exposures vary between individuals
- There are a wide variety of individual characteristics that explain these differences.
- Some risk factors for increased physiological responses are modifiable, whilst others are not.

### Recommendations

- Educate yourself and others (especially new recruits) on the internal and external risk factors.
- Understand how you and others (especially new recruits) respond to exercise-heat stress and use this information (e.g. sweat rate) to personalise preparation and recovery strategies.
- Abstain from alcohol consumption and recreational drug use the morning of and the day before heat exposure.

### Check your knowledge

1) Name 5 individual factors than may increase the risk of heat illness?
2) What medication might be a risk factor?
3) How might you reduce the risk of experiencing a heat related illness?

### Signs and Symptoms

During a fire exposure individuals are at risk of developing an exertional heat illness (EHI). There are numerous types of heat illness that range in severity, see Table 3 for an overview.

***Table 3.*** *Characteristics of heat related illnesses, from Lipman et al. (2013).*

| Condition | Definition |
|---|---|
| **Hyperthermia** | A rise in body temperature above the hypothalamic set point when heat-dissipating mechanisms are impaired (by clothing or insulation, drugs, or disease) or overwhelmed by external (environmental) or internal (metabolic) heat production. |
| **Heat oedema** | Dependent extremity swelling |
| **Heat cramps** | Exercise-associated painful involuntary muscle contractions during or immediately after exercise. |
| **Heat syncope** | Loss of consciousness, This is due to a fall in blood pressure and reduced blood flow to the brain which causes fainting to occur. |
| **Heat exhaustion** | The most common illness. Mild-to-moderate heat-related illness caused by exposure to high environmental heat or strenuous physical exercise. Signs and symptoms include intense thirst, weakness, discomfort, anxiety, dizziness, syncope; core temperature may be normal or slightly elevated to >37°C <40°C. |
| **Heat stroke** | The most serious and severe heat-related illness characterized by an uncontrollable rise in core temperature (>40°C) and central nervous system abnormalities such as altered mental status (encephalopathy), seizure, or coma. These can result from passive exposure to environmental heat (classic heat stroke) or strenuous exercise (exertional heat stroke). |

It is important to identify the signs and symptoms of minor heat illnesses because this can prevent the onset of the life-threatening condition of heat stroke. The figure below shows how minor heat illnesses can escalate into heat stroke (Figure 4).

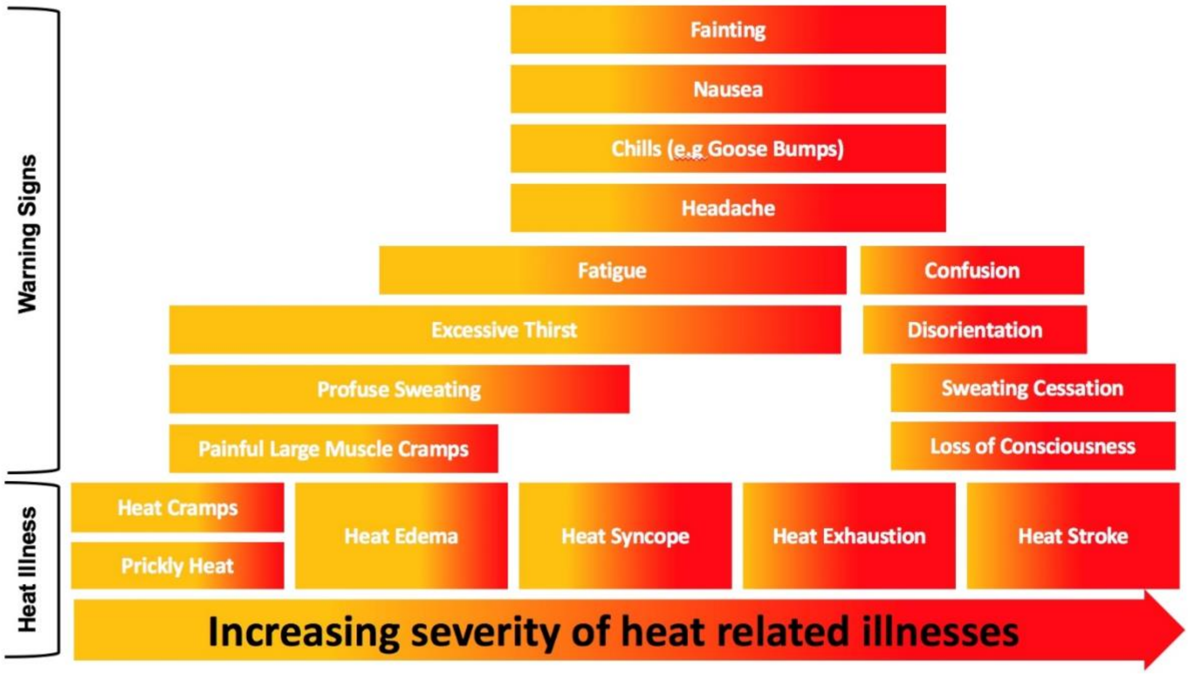


***Figure 4.*** *signs and symptoms of heat illness*

Between a Tc of 37 ºC and 40 ºC heat exhaustion can occur, with symptoms including fatigue, dizziness, heavy sweating, nausea, vomiting, a headache, fainting and clammy skin, although crucially cognitive status is maintained (Howe & Boden 2007). During a live fire situation an individual presenting with heat exhaustion would need to be immediately removed from the fire, as although not life threatening in themselves, symptoms such as fainting and dizziness could result in injury during an exposure.

If heat exhaustion is unnoticed or untreated it can develop into heat stroke, which usually occurs when Tc ≥40º C and is accompanied by a disturbance of the central nervous system, in the form of confusion, convulsions, or coma (Bouchama & Knochel 2002). Confusion and disorientation during a fire exposure can also be life threatening, as it could result in individuals being unable to remember their way out of a building, reduce their hazard awareness, and potentially put fellow crew members at risk. Heat stroke can progress into multi-organ system failure, with the risk of mortality increasing the longer an individual's Tc is elevated above 40.5 ºC (Casa et al. 2015). Electrical conduction abnormalities within the cardiovascular system may occur, which can cause heart attacks to occur (Akhtar et al. 1993; Chen et al. 2012). Musculoskeletal damage can also occur through the destruction of muscle cells (Bouchama & Knochel 2002; Bagley et al. 2007) . This causes proteins and myoglobin to leak into the circulation, resulting in blocked renal tubules within the kidney and ultimately acute renal failure if not treated (Bagley et al. 2007). Liver dysfunction is also common following heat stroke, and although rare, may develop into hepatic failure, which carries a poor prognosis (Trujillo et al. 2009).

There is a lack of records on the prevalence of heat illnesses amongst Fire and Rescue Service personnel in the UK. In the US heat illness is combined with other causes of fatalities into an overexertion/stress category, which is the leading cause of death amongst FF each year (Fahy et al. 2015; Fahy et al. 2017). However, this category also includes fatalities caused by cardiac events and therefore it is unclear what contribution is based on heat illnesses. A recent survey conducted in the US indicated that 22 out of 34 fire departments had at least one case of heat illness in the previous year, with 7 reporting the need for patient hospitalization, and 1 department reporting a fatality (Bach et al. 2018). Within the US military 5,246 Army soldiers were hospitalized from heat illness between 1980 and 2002, with 37 deaths, equivalent to 0.3 per 100,000 soldiers per year. Although hospitalization rates over the period studied reduced, the number of heat stroke incidents increased eightfold (Carter et al. 2005). This clearly indicates that those exercising in protective clothing are at risk of heat illness. Reducing the $T_c$ achieved during live fire exposures could minimise this risk.

It is recommended that $T_c$ is monitored throughout a fire exposure and during recovery if possible. Alternatively, $T_c$ pre and post exposure should be measured to ensure individuals are not at an increased risk of EHI when they start and to identify those who need to us cooling interventions. Individuals presenting with a $T_c$ ≥39.0°C post exposure should be monitored throughout cooling and reassessed after 20-30min.

**Treatment**

Upon the acknowledgment of any heat illness symptom firefighters should;

- Remove themselves from the source of heat if possible
- Seek shade and avoid direct exposure to the sun
- Dress down if possible
- Drink 1 litre of fluid, containing electrolytes and avoiding caffeine and alcohol

The following may be used to cool down further (in order of effectiveness, (Figure 5):

- Ice or cold water immersion will cool fastest, whole body or at least hands and feet (use a bowl or bucket with ice and water).
- Splashing yourself with cold tap water – face and arms.
- Placing yourself in front of a fan in the shade.
- Cold water soaked sheets on your body.
- Water and air spray around your body.

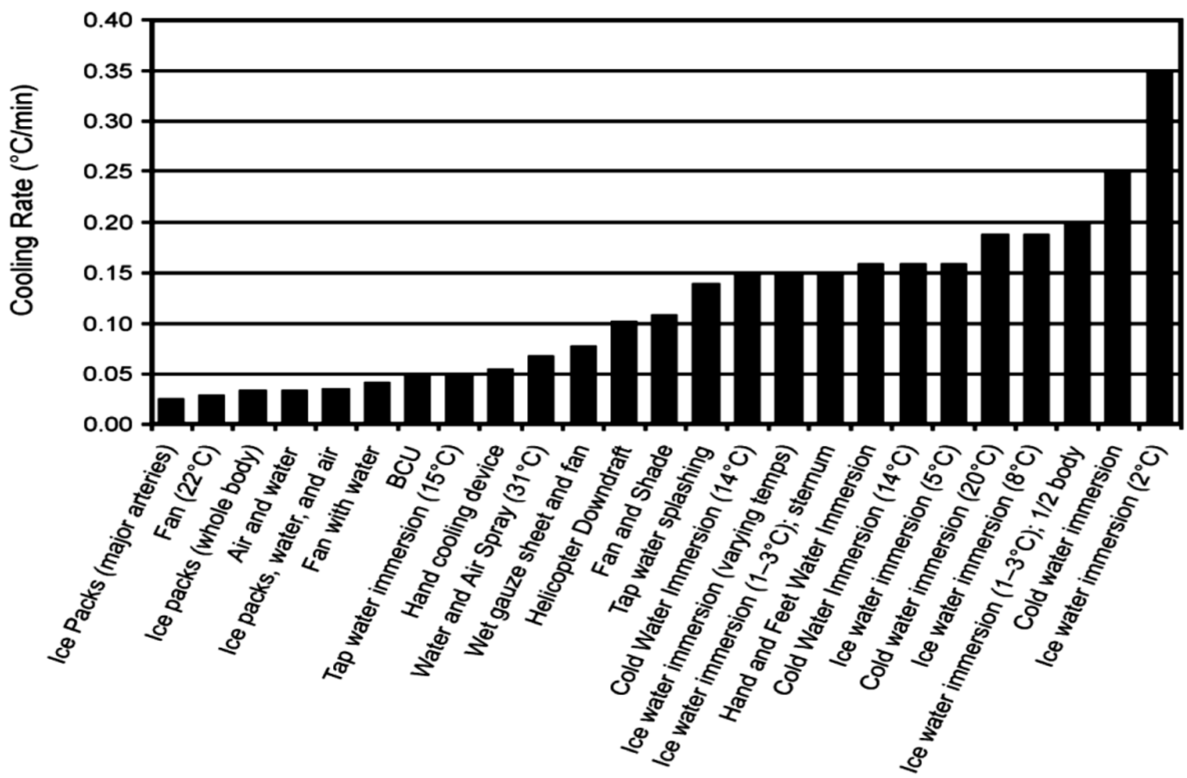


***Figure 5.*** *Cooling rates from different cooling modalities*

Post cooling has been widely studied within military and fire service populations. Cold water immersion (15ºC to the umbilicus) and ice slurry (7g.kg body mass$^{-1}$) ingestion have been recommended as the most effective cooling modalities, having been noted to reduce $T_c$ by 0.093ºC.min$^{-1}$ and 0.092ºC.min$^{-1}$, respectively, following a simulated 2x20min fire search and rescue task (Walker et al. 2014). Walker et al. (2014) also reported that both methods successfully reduced $T_c$ to baseline measurements within 15min. Due to the logistical difficulties of cold water immersion, ice slurry use is recommended as a post cooling intervention following a wear (Walker et al. 2014). Forearm post cooling has also previously been advocated within fire service communities (Chief Fire Officers' Association 2015), however a recent review of forearm immersion studies suggests it demonstrates inadequate cooling rates, with all studies reporting cooling of <0.078ºC indicating it would take >40min to cool an individual with hyperthermia (42.2ºC) to a safer level (38.9ºC) (Brearley & Walker 2015). For mild heat exhaustion an ice slurry is the most effective, with forearm cooling offering some small benefits.

In the occurrence of heat stroke mortality can be prevented with immediate medical attention and cold water immersion, reducing Tc to <40 ºC within the first 30 min of symptom presentation is recommended (Casa et al. 2006; Adams et al. 2015). $T_c$ should be cooled to 38.9°C, any lower may result in an after drop in $T_c$ with potential hyperthermia. If $T_c$ cannot be monitored no more than 20min of cooling should be administered, based on a TACo method cooling rate. The tarp-assisted cooling (TACo) method has been recommended to give similar results to cold water immersion in a tank, with a cooling Tre of 0.17°C.min$^{-1}$, and is achievable by holding up the sides of a tarpaulin sheet to create a make-shift tank to place the casualty in (Hosokawa et al. 2016). It is recommended to use an item of clothing placed under the arms to ensure their head is held above the water. Individuals may take time to recover from heat stroke, with weeks to months needed for a full recovery (O'Connor et al. 2010). The earlier cooling and treatment occurs, the better the prognosis in terms of recovery time (McDermott et al. 2007).

Although some symptoms may seem obvious, due to the serious health consequences of heat illness it is important that all Fire and Rescue Service personnel are aware of them and also know what treatment to implement. The poster below may therefore be useful to display (Figure 6).

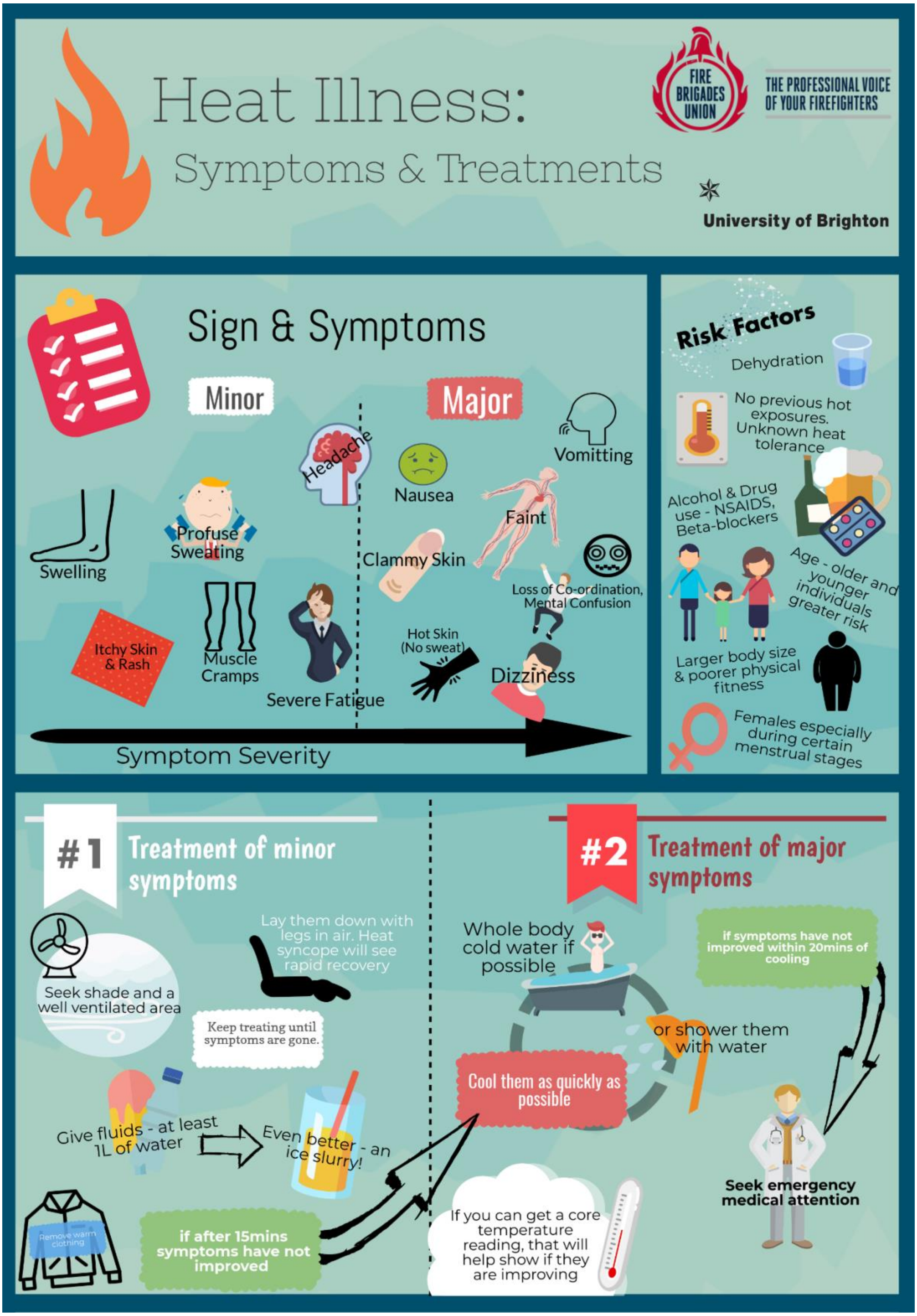


Figure 6. Heat illness signs and symptoms and treatment options.

### Return to Work After Heat Illness

Following a heat stroke return to work should occur through a process of steps (Casa 2018). Initial cause of heat stroke should be evaluated and medical clearance should be given. Gradual return to physical activity should occur over 2-3 months, with modifiable risk factors targeted for improvement if necessary/possible (eg. body composition, aerobic fitness). Ideally a heat tolerance test should then be performed 3 months after initial return to physical activity. If the test is failed it should be repeated at 2-3 month intervals for a further 2 attempts. If all tests are failed genetic evaluation for non-modifiable risk factors should be considered. Once a tolerance test has been successfully passed gradual progress back to full work should occur with body temperature monitoring conducted for the first 2-3 weeks to ensure $T_c$ remains in safe limits. However, currently the performance of heat tolerance tests is limited by the accessibility of specialist equipment and laboratories. It is important that return to work is therefore led by advice from medical and occupational health professionals.

## Key Points

- Prevention and treatment plans for all heat related illnesses should be prepared.
- Heat illnesses can progress from minor to life threatening if not treated quickly and effectively.
- Heat stroke, the most dangerous form of heat illness, is determined by central nervous system alterations and a high core temperature (>40.5°C).
- Return to work following heat stroke should be led by medical advice.

## Recommendations

- Remove individual from heat exposure and follow dress down procedure in shaded area.
- Post cool with ice slurry consumption.
- If heat stroke occurs use cold water immersion or TACo method to cool to 38.9°C or for no longer than 20 minutes if not temperature monitoring.

## Check your knowledge

1. What are the main heat related illnesses, from low, medium to high severity?
2. What are the key warning signs for heat related illnesses, from low, medium to high severity?
3. How can you treat heat stroke?

## HYDRATION

Maintaining a hydrated state is critical to maintain sweat rates and blood volume to enable heat dissipation. A dehydrated state can lead to increases in physiological strain, with 0.12-0.25ºC increase in $T_c$ and 3-5 b.min$^{-1}$ increase in HR for every 1% of body mass lost through sweating (Sawka et al. 2001; Casa et al. 2010). Decreases of 1-3% of body mass can cause decrements in both psychological and physiological performance (Cheuvront & Kenefick 2014).

Dehydration to >2% body mass loss impairs cognitive performance, with tasks requiring attention or executive function being more impaired than memory and reaction time. In addition, tasks needing motor coordination are significantly impaired with dehydration. Consequently, difficulty performing large motor skills or tasks such as finger/hand movements in response to a stimulus may occur. Accuracy is also effected by dehydration. Overall, as dehydration increases cognitive capacity becomes limited (Wittbrodt & Millard-Stafford 2018).

Rehydration following an exposure is also of particular importance, so that individuals they do not begin subsequent exposures in a dehydrated state. FSI have previously been noted to have a sweat rate of 0.86 - 1.59 L.h$^{-1}$ during a wear (Eglin et al. 2004; Watt et al. 2016). Whilst this commonly equates to <1% loss in body mass, FSI have on occasion be noted to exhibit 3.1% loss in body mass coinciding with dizziness and nausea (Eglin et al. 2004). Guidance states that individuals should consume 1-1.5 times the amount of sweat lost (Coyle 2004; Sawka et al. 2007; Chief Fire Officers' Association 2015). Replacement of two-thirds or total amount of fluid loss has been reported to enable exposure times to a treadmill walk in PPE to increase by 20% before a $T_{re}$ of 39.5ºC is reached (McLellan & Selkirk 2006).


***Figure 7.*** *Calculation of sweat loss and amount to drink*

It is also suggested that electrolytes be added to the fluid consumed to replace those lost through sweating and aid fluid retention, with a recommended 20-40mmol.$L^{-1}$ of sodium recommended (Coyle 2004; Sawka et al. 2007). The use of a colour chart to monitor hydration status is also suggested (Chief Fire Officers' Association 2015). Daily hydration is also key to acknowledge, with individuals guided to drink around 2-3 litres per day, when heat exposure and exercise is involved individuals should add an extra 1-2 litres on top of this to maintain a hydrated state. It is important to note that alcohol intake, although a fluid, is dehydrating. This means that extra hydration strategies (more water to be taken in) should be implemented the following day to ensure euhydration to reduce the risk of heat illness for heat exposures. Individualized prescriptions must be mindful of how much fluid can be absorbed by the body (~1.2 L per hour). Therefore, over-hydration may not be beneficial and may lead to more serious health consequences of an imbalance of salts in the body (i.e. hyponatremia) where the consequence is far greater than dehydration.

The sensation of thirst should not be relied upon for hydration strategies, due to when you feel thirsty you are already 2% dehydrated. It is useful to constantly monitor the colour of your urine throughout the day and daily with the aim to maintain a urine colour of 1-3.

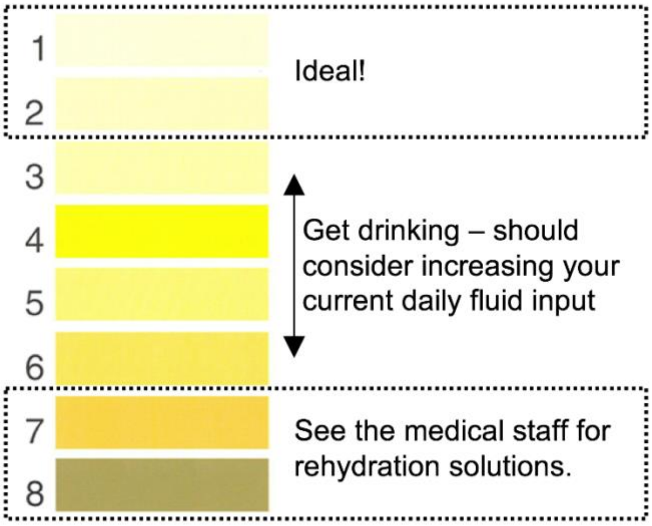


***Figure 8**.Urine colour chart*

## Key Points

- Daily hydration guidelines include the ingestion of 2-3 litres of fluid per day, and can be topped up with additional 1-2 litres if exercise-heat stress is undertaken
- Dehydration increases the chances of exertional heat illness.
- Dehydration can reduce decision making capabilities.
- Sweat rate in a fire exposure is typically 1-1.5 litres per hour

## Recommendations

- Check urine colour chart to monitor your hydration level.
- Following exercise heat stress, firefighters must rehydrate with 150% of fluid loss within 30-minutes
- Total sweat loss and, or sweat rate should be calculated to accurately determine fluid rehydration strategies
- Firefights must start exercise-heat stress duties in a hydrated state, achieved through the ingestion of 500 mL of water 30-minutes prior to arrival.
- Supplementing water with electrolytes (e.g sodium) may promote fluid ingestion rate, help gut absorption and conserve fluid retention.

## Check your knowledge

1. Using the 1-8 point urine colour chart, what levels are classified as hydrated?
2. How much should you rehydrate following heat exposure?
3. What else can be added to water to help retain ingested fluid post heat exposure?

## COOLING PRACTICES

Cooling interventions used pre and during (per cooling) exposure to the heat are common within sporting populations to reduce physiological strain and improve performance, with numerous reviews providing details of effective methods (Ross et al. 2013; Tyler et al. 2013; Bongers et al. 2014; Jones et al. 2012). Methods commonly fall into one of two categories, external, the application of cooling modalities to the skin, or internal, the ingestion of cooling substance, although some methods use a combination of the two (Ross et al. 2013). Pre-cooling aims to significantly lower initial $T_c$ and increase the body's heat storage capacity, thus increasing the time taken to reach a critical temperature and prolonging exercise duration (Ross et al. 2013). As long as a sufficient heat sink is developed (~0.5-1.0°C) then pre-cooling should be effective.

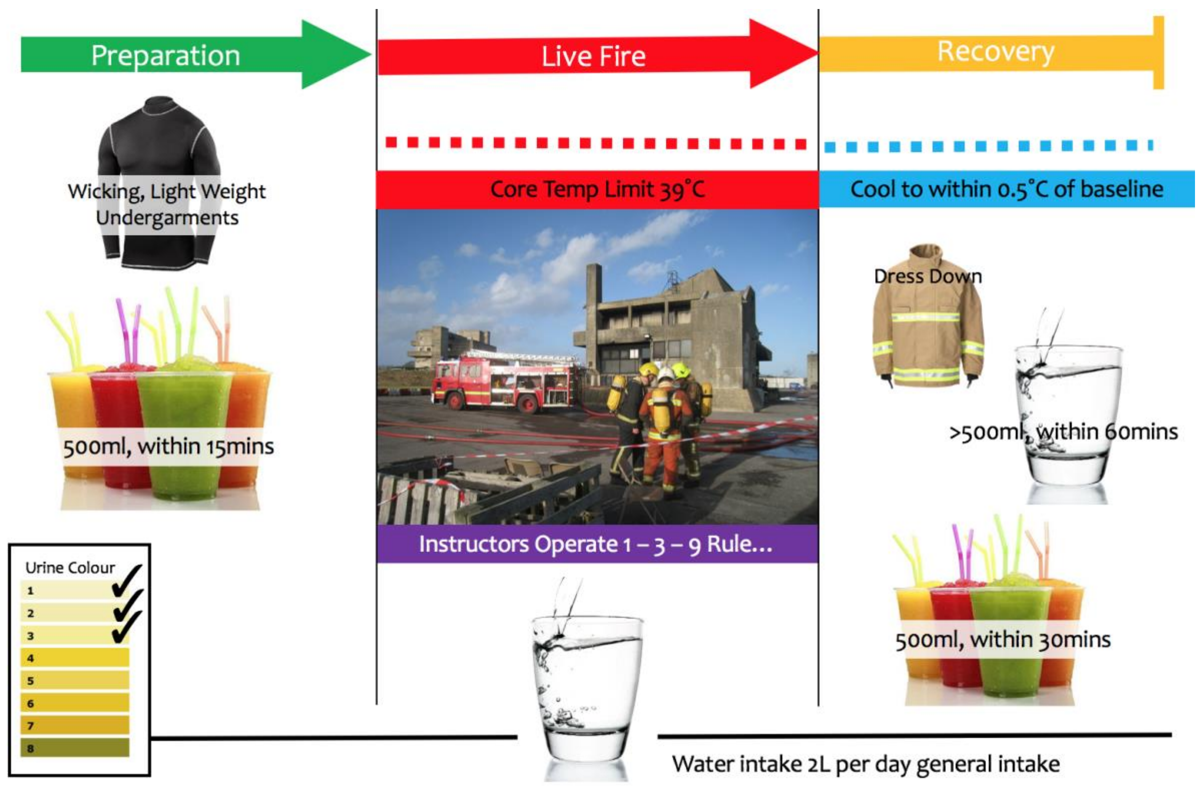


***Figure 9**. schematic of preparation and recovery to live fire exposure.*

Using pre-cooling has previously been suggested by the Chief Fire Officers' Association (2015). A review by Brearley (2012) suggests that ice slurry consumption prior to exposure may be beneficial for fire service personnel, as the potential heat storage conferred from crushed ice (489 $kJ.L^{-1}$) is greater than that of cold water (155 $kJ.L^{-1}$), whilst being easy to administer due to the minimal equipment, labour, or cost involved. A study by Pryor et al. (2015a) identified that pre-cooling with ice slurry reduced $T_{re}$ by ~0.6ºC prior to completing a treadmill walk in 38.8 ± 1.2ºC in wildland firefighting equipment, with $T_{re}$ remaining reduced for 30min. Furthermore, a recent assessment of pre-cooling methods, including a Drager phase change vest, forearm immersion, and 500ml ice slurry consumptions, conducted 15min prior to a laboratory simulated fire exposure reported that only ice slurry consumption effectively reduced $T_c$ prior to exposure (-0.24 ± 0.09°C). Ice slurry consumption also reduced core temperature and thermal sensation for up to 30min of exposure (Watkins et al. 2018).


Per-cooling is often used within breaks in play or during continuous exercise to limit the rise in $T_c$ and has been noted to improve exercise performance by 9.9% (Bongers et al. 2014). From an occupational perspective per-cooling is not feasible during a wear, due to the nature of the tasks being completed and the PPE and BA preventing application of either external or internal methods. However cooling where possible between wears is encouraged.

Consideration should be given to the location of any ice machines. Ideally they should be positioned in "clean" areas, and useable without possible contamination from "dirty" hands or gloves. See Figure 10. for suggested slurry machine.

***Figure 10.*** *Ice slurry machine in use by some training centres.*

## Key Points

- There are various internal (e.g. ice-slurry) and external (e.g. local and full-body cold-water immersion, wet towels, fans, ice vest, packs and pops) cooling strategies which can be undertaken, before, during and following exercise-heat stress
- Internal cooling strategies prolong tolerance time and reduce resting and exercising core temperatures (-0.5 to 1.0°C)

## Recommendations

- 15-minutes before heat exposure, consume 500 mL of ice with flavoured cordial to increase ingestion rate. Applying external cooling methods may also help.
- Cooling should be used between wears when possible.

## Check your knowledge

1. What are the benefits of pre-cooling, particularly ice-slurry ingestion?
2. What are some strategies of pre-cooling to lower core body temperature?
3. How long before heat exposure and how much ice slurry should be consumed?

## HEAT ACCLIMATION

An instructors' ability to complete tasks successfully in high ambient temperatures may also depend on their heat tolerance. Frequent exposure to increased temperatures can lead to heat acclimation occurring, whereby individuals have a lower HR, reduced rise in Tc, increased sweat rate and improved perceptual comfort when exposed to similar hot environments (Burk et al. 2012; Chalmers et al. 2014; Tyler et al. 2016). The physiological adaptions caused by heat acclimation increase an individuals' heat tolerance and reduces the risk of exertional heat illnesses occurring (McDermott et al. 2007; Cleary 2007; Lipman et al. 2013). Although it should be noted that heat tolerance does not protect individuals in all circumstances, for example during prolonged high intensity exercise in extreme heat when hypohydrated. In addition, the increased sweat rate may result in greater dehydration, therefore compounding the importance of maintaining a euhydrated state (Eglin 2007).

Research suggests that there is no difference between firefighter and non-firefighters for $T_c$ and HR responses to exercise in the heat (Wright et al. 2013). This similar tolerance between the groups suggests that firefighter's exposure to heat stress is not frequent enough for heat acclimation to occur. Ashley et al. (2015) suggests that individuals working in hot environments (50ºC, 20% RH) may take 6.1±1.4 days to acclimate. Assessment of instructors heat tolerance levels indicates that they may develop an acclimated status through their occupational levels of exposures, as they display reduce $T_c$, reduced HR, and an increased sweat rate in comparison to non-wearing individuals (Watkins et al. [unpublished data]).

### Heat acclimation strategies

There are numerous heat acclimation strategies that could be implemented to improve heat tolerance. Acclimation strategies could benefit new recruits prior to their first heat exposure course. However, as fire exposures are infrequent for operational firefighters, developing and maintaining an acclimated status in preparation for an emergency call would not be logistically feasible or recommended.

A minimum of five dedicated heat acclimation sessions (~60-100-minutes of passive or exercise exposure in the heat) would need to be implemented to evoke the benefits of physiological and perceptual adaptations. Longer duration acclimation protocols (10+) can elicit greater levels of adaptations. The aim of each session is to stress the body through sustained elevations in $T_c$ and skin temperature, and the promotion of profuse sweating. Traditional heat acclimation protocols include repeated exercise exposures to heat stress in confined laboratory or natural settings. Completing traditional protocols may be limited by cost, facility and equipment availability.

Alternatively passive strategies can be used to develop an acclimatised state without the need for laboratory facilities. Exposure time to the different methods would be expected to increase as an individual acclimates.

Alternative passive strategies are:

- Hot water bathing:
    - In 40ºC (measured via a floating pool thermometer) for 20-40-mins alongside or immediately after training
- Sauna exposure:
    - In 80°C, 20% relative humidity 40ºC for 20-40-mins alongside or immediately after training
- Restricting heat loss during regular training:
    - Wear an upper- or full-body sauna suit during routine training for 20-40-mins

➔ Session frequency

- Complete once-daily over consecutive days or every other day (minimum 5 exposures over 2 week period).

**Acclimation decay**

Important adaptations such as reductions in resting core temperature and heart rate, have been shown to reduce 2.5% for every day without heat exposure (Daanen et al. 2018). As a guide, it is likely adaptations are still evident 2-3-weeks following acclimation. Nonetheless, it has been suggested that for every 2-days absent from heat exposure, 1-day of adaptation is lost.

Overall, being heat acclimated may be beneficial to instructors, as it decreases the amount of physiological and perceptual strain they experience, and may reduce the risk of heat illness. Instructors develop an acclimated state as part of their normal operational exposure. Passive acclimation strategies could be used by new recruits to lower the risk of exertional heat illness prior to their initial fire exposures. Alternatively, courses could gradually increase the level of exposure experienced by recruits to enable acclimation to develop.

**Key Points**

- Instructors develop an acclimated state through their occupational exposures.
- New recruits could use passive acclimation sessions to improve their heat tolerance.
- A minimum of five dedicated heat training sessions should be implemented by individuals.

## CARDIOVASCULAR EVENTS RISK

During a fire exposure individuals are 12 to 136 times more likely to die of coronary heart disease than during any other duty (Kales et al. 2007). Cardiac death has accounted for 42% of Firefighter deaths in America in 2012, which rose to 56% of deaths in 2014, and is the main cause of fatalities in any given year (Fahy et al. 2013; Fahy et al. 2015). However, Fahy et al (2013) noted that age and obesity may be contributory factors, with cardiac death rarely occurring in firefighters under the age of 35yrs unless they had underlying medical conditions. Despite this, the high incidence of myocardial infarction makes cardiac strain experienced by firefighters a major concern (Cheung et al. 2010; Yang et al. 2013).

There are numerous possible causes of cardiovascular events as a consequence of firefighting. Prolonged heat exposure combined with physical activity causes high levels of cardiovascular strain and can reduce myocardial function, with both reduced systolic and diastolic function, which may be caused by mitochondrial damage and reduced contractile function (Fernhall et al. 2012). Three hours of live fire training exercise, including four to five fire exposures lasting 15-25 min, can result in a 13% reduction in stroke volume and alterations in left ventricular function (Fernhall et al. 2012). Myocardial function could also be reduced due to damage to the myocardium. Cardiac troponins act as biochemical markers of myocardial damage and are structural regulatory proteins that control the interaction of actin and myosin within the myocardium, they are unique to the heart (Sharma et al. 2004; Reichlin et al. 2009). Fire exposure has been noted to increase in cardiac troponin (1.5 $ng.L^{-1}$ to 3.0 $ng.L^{-1}$) in firefighters (Hunter et al. 2017) and in instructors (3.99 $ng.L^{-1}$ to 5.44 $ng.L^{-1}$) (Watkins et al [unpublished data]). Cardiac troponin prevalence in the general population is usually low and often below the detectable limits, with detectable levels associated with structural heart disease and cardiovascular events. Elevated cTnT post marathon have been linked to reductions in right ventricular function (Neilan et al. 2006). Exhibiting an increased cardiac troponin T (cTnT) (≥14ng/L) at rest is associated with an increase in all-cause mortality (hazard ratio = 2.8) and cardiovascular mortality (hazard ratio = 1.7) (de Lemos et al. 2010). However, the level noted in firefighters and instructors suggests only low level myocardial damage.

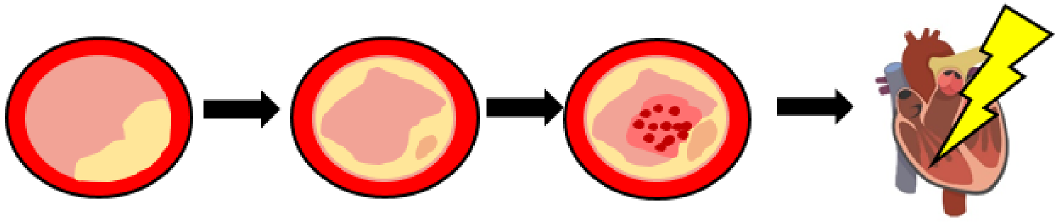


***Figure 11.*** *Development of atherosclerosis resulting in heart infarction*

Firefighting may also increase the risk of cardiovascular events via atherosclerosis, which is the formation of plaques that result in blood vessel narrowing or thrombi that obstruct blood flow (see Figure 11) (Bentzon et al. 2014). The occurrence of atherosclerosis may be related to platelet number and size, and the presence of inflammation. A live fire training exercise of 20 min has been noted to increase platelet number by 30% and thrombus formation by 66-73% (Hunter et al. 2017). These findings are supported by Smith et al. (2011) and Walker et al. (2015) who also report increased platelet counts post fire exposure. A slight increase has been documented to remain present at 24hrs post wear (Walker et al., 2015).

Inflammation is also related to the presence of atherosclerosis. There are numerous blood markers of inflammation, which include messengers in the blood called interleukin-6 (IL-6). Firefighting search and rescue tasks have been reported to cause increases in IL-6 (Walker et al. 2015). A 45 min wear conducted by instructors has also been noted to elicit 34% increases (Watt et al. 2016) and 28% increases (Watkins et al [unpublished]) in IL-6. This occurs as a consequence of the increase in $T_c$ and physical exercise. Elevated resting IL-6 levels has also been documented with frequent fire exposure, with levels of 11.4 ± 1.0 pg.mL$^{-1}$ following a 4 week period of instructing courses. This is much greater than the resting level recorded in healthy individuals of 1.46 pg.mL$^{-1}$, and in the upper range of IL-6 (>2.28 pg.mL$^{-1}$) where the risk of a cardiovascular event is 2.3 times those with low IL-6 (<1.04 pg.mL$^{-1}$) (Ridker et al. 2000).

**Key Points**

- Firefighters are placed under an increased level of physiological strain during exercise heat exposures, which can lead to an increased susceptibility of cardiovascular related morbidity and mortality.
- Firefighters with a lower aerobic capacity (e.g. fitness levels), family history of cardiovascular events, and an increased body mass (particularly fat mass) are at a greater risk of adverse health events during fire exposures.
- Undergoing hydration and cooling strategies before and following heat exposure, can help mitigate the magnitude of physiological strain experienced.

## INSTRUCTOR HEALTH

Instructors also experience more symptoms of ill health than firefighters, with 41% of instructors reporting getting new symptoms of ill health since starting their job in comparison to 21% of firefighters (Watkins et al. 2018). A common set of symptoms are experienced by FSI, which includes: fatigue, headaches, broken sleep, heavy sweating, mood swings, coughing/breathing problems (Watkins et al. 2018). These are similar to the symptoms of overtraining, which is usually reporting in a sporting population when large volumes of high intensity training are combined with minimal recovery time. Alongside symptoms of ill health overtraining can also involve chronic inflammation and a reduction in performance capabilities. Watt et al (2016) reported a 7% reduction in $VO_2$ max and a reduction in lung volume following a 4 week instructing course. Furthermore, the greater the number of fire exposures completed in a month, the greater the level of inflammation detected in instructors.

This increase in inflammation also suggests that instructors may be at an increased risk of a cardiovascular event. Recent research indicates that instructors have an increased (+32%) resting levels of cardiac troponin, and also have increased blood markers, such as interleukin-6 (+166%) and C-reactive protein (+108%) that are predictors of cardiovascular events, in comparison to firefighters. Instructors that complete greater than 9 wears a month are 6-7 times more likely to be classified as at a high risk of cardiovascular event than those with a lower wear number (Watkins et al [unpublished data]).

***Figure 12***. *Instructor photo courtesy of Chris Sirett*.

In addition, elevated inflammation in instructors' results in them being 8.61 times more likely to experience symptoms of ill health than instructors with lower levels. Increased wear numbers in a month is also linked with the occurrence of symptoms of ill health. However, monthly wear numbers are related to maintaining heat acclimatized status; instructors have been found to demonstrate an increase in heat tolerance similar to that noted following heat acclimation compared to a non-wearing control group. Consequently, a balance should be sought between maintaining an increased tolerance to heat and preventing inflammatory and ill health maladaptation. A limit of 9 wears a month may minimize the occurrences of ill health. When instructors return from any long breaks or leave, their heat tolerance may be reduced and consequently may experience high physiological strain following heat exposure.

Furthermore, research indicates that a multiple compartment exposure results in a greater increase in $T_c$ than lay flat attack box exposures (+0.26°C) (Watkins et al. 2018 [unpublished data]). Being a condition setter in a multiple compartment exposure also results in a greater $T_c$ than being an inside instructor (+0.20°C) (Watkins et al. 2018 [unpublished data]). Consequently, it is important that instructor roles are rotated during a course. Overall, instructors specifically should ensure take precautions to reduce the total thermal load they are experiencing over the period of their career. This includes closely following hydration and cooling guidance to minimize the increase in $T_c$ that occurs with each exposure.

## Key Points

- Fire service instructors suffer from increased symptoms of ill-health compared to firefighters.
- Typical symptoms include; chronic-fatigue, headaches, disrupted sleep, heavy sweating, mood swings, and respiratory problems, and are coupled with reductions in aerobic capacity and increased levels of inflammation, which raises the risk of a cardiovascular event.
- Fire service instructors who complete more than 9 heat exposures per month are at a greater risk of ill-health and cardiovascular consequences.

## Recommendations

- Use pre-cooling strategies to reduce risk of heat illness and overall thermal load
- Follow hydration guidelines to prevent dehydration
- Fire service instructors should rotate roles during fire courses
- Limit wears to 9 per month

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