

Occupational heat exposure

Part 1: The physiological consequences of heat exposure in the occupational environment

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ABSTRACT

Heat in the occupational environment is a common hazard and with increased industrialisation, deeper mines and imminent climate change due to global warming is sure to become a larger occupational health and safety risk in the future. This paper, the first in a series of two papers on heat exposure presents some recent developments in the area of occupational heat stress and heat illness and the human physiological response to heat such as, sweat rates, electrolyte loss and the effects of dehydration.

INTRODUCTION

In any work environment where industrial processes create heat the risk of heat-related illness with increased environmental heat loads on workers is increased, especially in deep underground mines or where naturally occurring ambient climatic conditions are prone to extreme heat episodes and high humidity levels. In these

environments workers have to maintain normal body temperatures (within 1 or 2°C) in order to work without developing heat illnesses for shifts of up to 12 h. The purpose of this paper is to present some recent developments in the current knowledge of occupational heat stress and heat illness and the human physiological response to heat. References from recent peer reviewed research sources have been used to support the presentation and discussion of heat stress research that would be of practical use to OHS practitioners.

THERMOREGULATION AND THE HEAT BALANCE EQUATION

Body core temperature is the result of the balance between those processes that create body heat and those that dissipate heat. The formula below has been shown to approximate how the body's thermoregulatory system works:

$$S = M + R + Cd + Cv - E$$

S = stored heat

M = metabolic heat production

R = amount heat gained or lost by radiation

Cd = conductive heat lost or gained

Cv = convective heat lost or gained

E = evaporative heat loss

From this formula¹ it is evident that heat balance in the body depends upon the amount of heat produced by muscle activity and metabolism and the amount of heat that is gained or lost either by the effect of the environment and evaporation of perspiration. Dripping sweat that does not evaporate does not significantly contribute to heat loss. Air movement and velocity aid the cooling of the body and



are thus important parameters for control of heat build-up in the body and effective cooling.

Risk factors for heat illness can be classed into two categories: heat stress is the environmental parameters that impose a heat load on the human body and heat strain is the response of the body to the heat load derived from the environment.¹ Personal factors are classified as those factors which can impact on the ability to maintain thermal stability and influence strain outcomes. These are the individual factors of a worker such as, age, fitness levels, body composition, degree of acclimatisation, health status, fluid consumption, alcohol and caffeine consumption, which can affect hydration status, and the use of some medications.

PHYSIOLOGICAL RESPONSE TO HEAT STRESS

When a worker is exposed to high levels of heat and humidity the body reacts by increasing the heart rate, stroke volume and therefore cardiac output.² However, a significant amount of this blood flow will be diverted

to the peripheral circulation to dissipate heat to the surrounding environment. The circulating blood diverted to the periphery reduces the amount of oxygenated blood going to the metabolically active muscles thus decreasing the work capacity of the worker. Internal heat in the peripheral circulation is lost to the environment by way of active sweating in an attempt to maintain thermal homeostasis, which leads to progressive water and electrolyte loss over time.³

ACCLIMATISATION

Acclimatisation is the process where the body adapts to or becomes accustomed to increased heat exposure. It depends upon the activity level of the person in the heat as well as the duration of heat exposure. Generally 14 days is adequate to provide a significant level of acclimatisation but within 4–5 days the acclimatisation process has been initiated and progressed to a reasonable level. Some benefits of acclimatisation include:

- reduction in sodium loss in sweat by up to 50%⁴;

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- a quicker initiation of sweating on exposure to heat⁵;
- increased sweat rate⁶ and more efficient body cooling;
- reduction in lactate accumulation in blood and muscles⁷;
- reduction in heart rate and stroke volume^{6,7};
- decreased skin and core (rectal) temperatures^{6,8}; and
- hypertrophy of sweat glands (increase in size).⁹

TYPES OF HEAT ILLNESS

When the environmental and metabolic heat loads exceed the ability of the body to dissipate the heat, various types of heat illness may develop with varying degrees of severity.

Prickly heat is a term used to describe skin inflammation, especially following profuse sweating. The sweat gland ducts become blocked and the sweat is forced out across the wall of the sweat duct into the subcutaneous tissue resulting in a red rash with small thin walled blisters containing a clear fluid (sweat) which can lead to infection. Thermoregulation is compromised in this state, and removal from the hot environment and good hygiene is often sufficient to eliminate or prevent the condition.⁷

Heat cramps are painful uncontrolled muscle contractions usually occurring in the gastrocnemius (calf muscle) or the biceps femoris (in the thigh area) and associated with working in the heat.¹⁰ Exercise induced cramps may occur in susceptible individuals. Donoghue et al.¹⁰



found that heat cramps are associated with dehydration in underground miners (though not hyponatraemia), and when observing football players prone to cramping, other authors indicate that sweat sodium losses and fluid deficits are more often found in players experiencing cramping.¹¹ These observations support a conclusion that fluid/electrolyte loss/imbalance is involved. Anecdotal evidence strongly suggests that optimal hydration levels significantly reduce the prevalence of muscle cramps.

Heat exhaustion is the inability of the blood circulation to meet metabolic and thermoregulatory demands. Generally speaking, persons who are unacclimatised, unfit, obese or dehydrated are more prone to this condition. Weakness, inability to continue working, frontal headache, anorexia, nausea, dizziness, and in some cases fainting are the usual symptoms. Often fluid intake and rest in a cool place will be sufficient to revive the individual, or intravenous infusion of fluid (normal saline/glucose) may be needed.¹⁰

Heat stroke is a life-threatening condition where the body's cooling ability fails and the temperature increases to dangerous levels. The development of this condition is a possibility in persons who are highly motivated to complete physical tasks or for those in paced labour in the heat, or highly competitive sports-persons. The mortality rate is approximately 80%, as the body attains a temperature that causes tissue damage and the brain, liver and kidneys are the principal organs affected. Heart rate and core temperature elevation, and the cessation of sweating are the usual physiological signals. Clinically heat stroke can be distinguished from heat exhaustion by unconsciousness often preceded by confusion or convulsions.¹⁰

The development of heat illness is related to increased environmental heat loads. However, other emerging issues in the modern workplace and personal factors also may affect thermal regulation which are becoming more prominent including: 1. increased levels of fatigue (with increasing workloads and stress levels as shift work and fly-in fly-out schedules become more common); and 2. increasing obesity levels through decreasing levels of recreational physical activity. At present over half the Australian and South African populations are considered to be overweight or obese.^{12,13} These factors will start to play a larger role in the development of heat illnesses and in the future will certainly increase the risks in workers.

BIOCHEMISTRY OF HEAT ILLNESS

Heat illness has many specific physiological effects that manifest themselves in various ways and are often related to the reduction in body fluids due to continual sweating. When blood samples of workers suffering from heat illness are taken, there is an increase in red and white blood cell and platelet concentrations due to lower plasma volumes associated with dehydration. Fluid

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volume depletion initiates sodium retention in the kidneys¹⁰ and sweat glands. Sweat is hypotonic to plasma. Therefore, prolonged sweating concentrates the blood and water is lost out of proportion to sodium, which the body attempts to conserve, this being a vital electrolyte in many biochemical and physiological functions. Fluid and sodium loss result in hypovolemia, which reduces the body's ability to dissipate heat which causes an increase in temperature.

HYPHYDRATION AND DEHYDRATION

Prolonged sweating will lead eventually to hypohydration or the more serious condition of dehydration, which is the excessive loss of body water. Signs and symptoms of dehydration include increasing thirst, dry mouth, weakness or light-headedness (worse on standing), and a darkening of the urine or decrease in urination. Severe dehydration can lead to changes in the body's biochemistry, kidney failure, and may become life-threatening.¹⁰

A worker exercising in heat can sweat in excess of 1.5 L/hr¹⁴ and over a 12 hour shift may lose over 10 L of fluid. Studies have shown a fluid deficit of up to 3.5 L² after a work shift. Both cognitive¹⁵ and physical function have been shown to diminish with hypohydration and dehydration^{6,16,17} and this in turn can influence productivity, work output¹⁸ and safety at work.

ELECTROLYTE LOSS

Substantial loss of sodium (Na⁺) via sweat can lead to body electrolyte reduction and disturbance, which in turn can impair muscle and neural functioning.¹⁹ An unacclimatised person may secrete sweat with a Na⁺ concentration of 64 mmol/L (CI 95%; 36-54) or 1.5 g/L²⁰ or higher and can lose large amounts of Na⁺ if sweating profusely for a prolonged period, such as occurs in shift work conditions. An acclimatised person on the other hand may secrete sweat with a Na⁺ concentration of 45 mmol/L (CI 95%; 55-72) or 1 g/L,²⁰ which is 50% less

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than an unacclimatised person. The 24-hour adequate intake (AI) level of Na⁺ for a normal young adult in the US is set at 1.5 g (65 mmol),²¹ in Australia at 490–920 mg (20–40 mmol)²² and South Africa at <2 g (87 mmol).²³ These values are for individuals not exposed to high temperatures and who lose large volumes of sweat and sodium.

FLUID AND ELECTROLYTE REPLACEMENT

There is a maximum rate at which fluid can be absorbed into the body, approximately 1.5 L/hr limited by absorption rates and gastric emptying.²⁴ Drinks with high concentrations of carbohydrate (sugar) and electrolytes (salts) are absorbed relatively slowly, and are thought to impede fluid replenishment.²⁵ Normal sodium loss from day to day does not require additional electrolyte supplementation, as a normal diet provides enough replacement sodium chloride.¹⁷ However, where sweat rates are high, and especially in unacclimatised individuals, the need to replace daily electrolyte loss at regular intervals is essential to avoid electrolyte disturbance and impaired performance.

Some commercially or self prepared drinks such as cordials have varying concentrations of glucose and sodium which is added to the drinks for the purpose of replacing sweat salt losses, and to maintain blood glucose levels (energy). Consequently, the consumption of these drinks, if consumed as a sole replacement beverage results in excess sodium and glucose intake when quantities of up to 8–10 L/day are required in extreme heat stress conditions, i.e. a 12 h shift underground. On the other hand, if high sweat losses are replaced with plain water, dilution of the plasma may occur and inadequate plasma sodium concentrations could result in hyponatraemia.²⁵

A fluid replacement beverage must therefore promote water absorption at the maximum rate in order to counteract fluid loss associated with heavy sweating and it should be hypotonic (<300 milliosmolar), containing sodium (>12 mmol/L), potassium (~5 mmol/L) and glucose (>5 mmol/L). The correct ratios will promote maximal fluid uptake and absorption, replace electrolyte losses, and reduce fatigue by providing a ready source of energy for muscular work.²⁰

CONCLUSION

Heat stress is an important occupational hazard in industry. Along with environmental monitoring and exposure control measures, the combination of adequate hydration, electrolyte replacement, acclimatisation and the promotion of healthy lifestyles through education are all vital components in enhancing the health of workers in heat.

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