IDENTIFICATION AND MANAGEMENT OF THERMAL STRESS AND STRAIN

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ABSTRACT

In tropical climates and hot working conditions, high sweat rates with excessive loss of body fluids may result in dehydration and electrolyte imbalance. It is well established that dehydration and /or electrolyte disturbances will impair both mental and physical work performance and if prolonged or severe can pose a serious risk to the workers health. The lesser condition of hypo-hydration is undoubtedly wide spread amongst workers in North Queensland because of environmental conditions, as well as those undertaking hot work. In many cases it is undoubtedly indirectly responsible for less than optimal work performance, accidents, injuries, and illness associated with work.

A case involving the unexplained death of a mine contract worker in North Queensland is presented and used to illustrate some aspects of the identification and management of risk factors in both the worker and the workplace.

In an unrelated case in April 1999, a Brisbane company director was jailed for 18 months and the company fined $10,000 for ignoring a Workplace Health & Safety inspector's notice which resulted in the "accidental" death of a contract plant operator. This legislation bears some resemblance to new legislation entering the mining industry in that it no longer solely relies on compliance but requires development of specific, relevant risk management systems.

SUMMARY

This paper discusses briefly the implications of working in hot environments and offers suggestions for development of management policies and procedures. Attached as Appendix A is the outline of the case to be presented. It is based on fact, however where some details are unknown they have been substituted with fictional information selected to add to the impact of the presentation.

INTRODUCTION

Exposure to high temperatures while working is a common and potentially fatal occupational hazard. The body normally functions within a very narrow range of core body temperature (36.7°C - 37°C). Under conditions of heat stress, the combined effect of environmental heat, metabolic heat and impervious clothing can strain the body's ability to maintain heat balance, and the core temperature of the body may begin to rise causing physiological effects. In the workplace, heat exposure, in addition to causing heat related illness, has been found to decrease productivity and increase job related accidents. In any heat hazard environment, whether indoors or out doors, high ambient humidity or heavy manual labour, and other factors (Table: 1) can increase the workers risk for heat strain.

Table 1:
Factors Involving Man and Heat Stress.
[Zenz C., (5), p 1217]

External Factors
Air temperature & humidity
Temperature of solid surroundings (radiant energy)
Temperature of the skin
Air Motion
Type of clothing worn
Time exposed
Work factors (load, weight of equipment & tools, pace)
Human Factors
Age, sex, race
Size (mass, surface area)
Degree of muscle activity
Health status & individual fitness
Acclimatisation
Psychological Factors (incentives, rewards, discipline)

Heat exchange between the body and the environment is influenced by air temperature and humidity, skin temperature, air velocity, evaporation of sweat, radiant temperature and the clothing worn .

A steady state of thermal equilibrium is represented by the following heat balance equation:-

$$M - E +/- K +/- C +/- R = 0$$

M = Metabolic heat generated
E = Evaporative heat loss
K = Conductive heat exchange
C = Convective heat exchange
R =Radiative heat exchange

The heat balance equation incorporates the major modes of heat exchange or loss by the body. Heat exchange takes place by conduction, convection, radiation, and evaporative heat transfer. For normal body function, heat exchange between the body and it's environment needs to be balanced and practically relies on convection, radiation, and evaporative heat transfer. In hot environments where the ambient temperature approaches core body temperature (above 34^0 C) then radiation and convection as a means of thermoregulation become secondary to evaporation as a result of sweat loss. In situations of thermal stress where heat needs to be lost from the body in the workplace, contact area between the skin and solid objects is usually very small, therefore conduction as a means of heat exchange can be considered negligible except in the situation where body cooling garments are worn.

As the human body requires evaporative and connective heat exchange to dissipate most excess internal heat, factors that would reduce these modes of heat transfer would cause the core body temperature to rise, resulting in hyperthermia. High ambient humidity and clothing are the primary factors in diminishing heat transfer for workers. Humidity decreases sweat evaporation, and clothing, which insulates the body and skin form the surrounding area, impedes convective heat loss and interferes with the evaporation of sweat from the skin. Protective, especially impermeable clothing which effectively eliminates any body cooling from sweat evaporation, places workers at significant risk for heat strain and heat related illness. Individual factors (Table 2), as well as environmental may also be relevant.

Table 2:
Host Factors Reported To Increase The Risk Of Heat Stroke.
[Zenz C., (5), p 1217]

Unacclimatisation
Obesity
Poor Physical Fitness
Fatigue
Sleep Deprivation
Febrile Illness
Dehydration
Acute & convalescent Infections
Immunisation Reactions
Conditions effecting sweating
Skin Disease (heat rash, sunburn)
Drugs (alcohol, antihypertensives, caffeine)
Past history of heat injury
Past history of residence in areas with greater atmospheric cooling power
Chronic Disease (Diabetes, thyroid, cardiovascular)
Neurological Lesions (hypothalamus, brainstem, cervical chord)
Post surgery
Recent food intake
Sustained muscle metabolism

PHYSIOLOGICAL EFFECTS OF WORK & HEAT EXPOSURE

Metabolic heat is generated within the body by biochemical processes. At rest, the rate of heat reduction by the body is low (resting oxygen consumption 250ml per minute, corresponding to a rate of heat production of 70 Watts.m^{-2}. At high work rates the metabolic heat production can exceed 80KJ per/min (20

K/cal per/min) and highly trained individuals can sustain these work rates (1000 Watts. $.m^{-2}$) for several hours. With increasing work intensity, oxygen consumption increases to make the greater metabolic requirements. The body's mechanical efficiency is poor, with every litre of oxygen used during work producing approximately 4KJ of energy for mechanical work and approximately 16KJ of heat production. As a result, the amount of heat liberated under resting conditions may increase more than ten fold (5 to 20) under maximal work intensities (1). Investigation by Tranter and Abt of Central Qld University at North Goonyella in 1997-8 recorded average metabolic rates for underground miners of 100 Wm^{-2} with the peak rate averaging 300 Wm^{-2} (2). Work done by Gravelling, Hanson and others in Europe is consistent with these findings although in average situations perhaps a little higher (3). They have ranked underground activities with manual material transfer highest, followed by roof bolting and shearer or chock operation equivalent to walking (4).

The heat produced in working muscles causes considerable temperature increase of the muscle tissue. It is transferred from the muscle to the generally cooler circulating blood depending on the temperature gradient and the rate of blood flow. Blood transfers this heat to the periphery where another temperature gradient transfers the heat from blood to skin. Continued heat production increases the core temperature and sweat production is initiated to wet the skin for evaporative cooling purposes. Sweat production produced to maintain core body temperature results in loss of both water and electrolytes.

Depending on work intensity, and state of heat acclimatisation, sweat rates can rise as high as 2 to 3 litres per hour. If these fluids are not replaced this can result in increasing core temperatures and decreasing circulating blood volume. Loss of electrolytes, particularly sodium, and chlorine (more pronounced in unacclimatised individuals) can produce a number of adverse biochemical effects. At a fluid loss of as little as 2% of body weight there is an impairment in mental performance in all functions, such as short term memory, arithmetic efficiency, and also physical performance. The stress or effect of heat can be qualitatively determined by measuring increasing plasma cortisol levels. These are more pronounced in unacclimatised workers and increase further as hypohydration develops, indicating a high degree of physiological strain. Cortisol results in the utilisation of glycogen (energy) reserves faster than the normal rate, further compromising workers ability to perform optimally by reducing the threshold time before fatigue.

Thermal balance therefore involves the interaction between heat absorption from the environment, heat production by metabolic means within the individual, and heat loss through physiological means such as sweating. Although thermal balance can be achieved solely by physical means (reducing work output), at least in theory, physiological control is evoked whenever thermal balance is challenged. In essence, physiological thermoregulation is achieved through three main effectors:

1. Increase or reduction in metabolic rate to counter heat loss or gain to the external environment.

2. Vasomotor adjustments at either facilitate (dermal vasodilation) or restrict (dermal vasoconstriction) heat loss from the body.

3. Sweating which promotes evaporative heat loss.

Acclimatisation

On the first day of work in heat, great strain is placed on the thermoregulatory system. The sweat mechanism fails to meet its commitments and the cardiovascular system is required to increase the supply of blood to the skin to dissipate heat. This places increasing strain on the cardiovascular system and reduces blood supply to other tissues and organs. This is a consistent finding during heat exposure of unacclimatised individuals and is often manifested in fainting. As acclimatisation proceeds, the sweating mechanism improves relieving cardiovascular strain.

Acclimatisation leads to an increase in the body's ability to produce sweat, reabsorb electrolytes (producing increased but dilute sweat), and reduced secretion of cortisol in response to thermal stress. Other features of acclimatisation probably also include an expansion of the blood (plasma) volume following physiological changes retaining protein within the blood. It is never the less convenient to define heat acclimatisation as the physiological mechanism whereby thermoregulatory strain is transferred from the circulation to the sweat mechanism.

Pathological Effects

The spectrum of heat related disorders ranges from harmless skin irritation to potentially fatal heat stroke.

Heat Related Skin Conditions

Heat rash, or maliaria, is caused by sweat duct obstruction and results in sweat retention within the gland. This may result in infection or more commonly rupture within the skin with an inflammatory response resulting. Sunburned skin and occlusive clothing interfering with free evaporation of sweat increase the risk of this conditioning developing.

Heat Syncope (Fainting)

This commonly occurs in workers who are unacclimatised or have become dehydrated. It is caused when the cardiac output is inadequate to maintain cerebral circulation and consciousness. It may occur as a result of vasodilation, pooling of blood in dependent extremities, reduced blood volume (from dehydration) resulting in reduced cardiac output. It is not associated with an elevated body temperature.

Heat Cramps

These are painful muscle spasms that occur during or following intense physical exercise in hot environments. Muscles involved are usually the same muscles used during the proceeding exercise such as abdominal muscles or large muscles in the arms and legs. They probably result from changing concentrations of electrolytes, and may be associated with profuse sweating, drinking large quantities of water, or missed meals (inadequate salt and electrolyte replacement).

Heat Exhaustion

This is a complex of symptoms of fatigue, headache, nausea, and giddiness associated with finding of moist, clammy skin, rapid heart rate, low to normal recumbent blood pressure that may fall on standing, and usually normal or slightly elevated core body temperature. Heat exhaustion occurs as a result of either dehydration and/or electrolyte depletions. It is more common in unacclimatised workers. Treatment should be individualised based on the severity of the symptoms and the underlying cause. Return to work after heat exhaustion has not been fully studied but it seems prudent to allow at leat 24 to 72 hours for full rehydration and correction of electrolyte abnormalities to occur.

Heat Stroke

This is a life threatening medical condition. Symptoms include altered mental status and core body temperatures above 40°c. It occurs when the body's thermoregulatory mechanism is overwhelmed by internal or external heat load and results in increasing core temperature. Mental status changes are the predominant initial presenting symptom. Treatment for all heat stroke victims is immediate initiation of cooling and appropriate resuscitation. Biochemical investigation and monitoring is also required. The degree and duration of the elevated temperature determine the severity of sequelae and mortality in heat stroke. Multiple organ failure or disruption of function is common and should be expected. Renal, cardiovascular and nervous system damage in those that recover may be permanent.

CONCLUSIONS & RECOMMENDATIONS

- Heat Stress Measurement (6): As well as heat gain through metabolic effects the body may also gain heat from the external environment. This ambient heat may also effect the workers ability to dissipate body-generated heat to the environment. It is determined by four primary environmental factors: -

  - air temperature
  - air humidity
  - air movement or velocity
  - Radiant heat (this may be comprised of solar, inferred, or in some cases microwave radiation).

  Various measures of ambient heat load are available for use in occupational settings. The most commonly used being, dry bulb temperature and wet bulb globe temperature. These together with the measurement of air velocity are the basis of a number of heat stress indexes available to industry. Three of the more commonly used indexes are: -

- Effective Temperature
- Wet Globe Bulb Temperature (WGBT) Index
- Heat Stress Index.

Compact heat stress monitors with rapid response and sophisticated electronics, such as those currently under development for evaluating hot environments in accordance with ISO 7933 (7), will eventually make simple WBGT instruments and calculations obsolete. With this newer technology both static monitoring, and, , personal monitoring can now also be considered.

Until these are freely available then a stepped method similar to that described by Di Corleto could provide a simple structure with which to approach most heat stress situations (8). In underground coal mines there is no solar loading and little radiant heat generated except perhaps in the close vicinity of mechanical equipment. In these situations air humidity and consequently the wet bulb temperature is a more reliable means of determining heat stress. Although not satisfactory for critical areas, this measurement could be used as a quick, practical, and reliable guide as to whether more detailed monitoring is required, particularly for workers undertaking light work and not producing significant metabolic heat. In areas where exposure to radiant heat, fluctuating ventilation levels, and high physical demands are placed on individuals then more reliable and comprehensive thermal stress indicators are considered necessary. At present most of these indicators require some degree of arithmetic calculation, however with the advent of electronic calculators, computer software, and newer, more comprehensive heat stress monitoring devices then the application of these measures will become more practical.

- Heat Strain Indicators: As well as heat stress, indexes, based upon external heat measurements, physiological responses to environmental heat stress have also been used to evaluate worker heat strain and tolerance to heat exposure. The four main heat strain indicators are; heart rate, body temperature, skin temperature, and hydration status. Historically the nature of the monitoring equipment, its lack of durability, and requirement for skilled interpretation have made real time measurements of workers core body temperature, heart rate and hydration status impractical. While continuous monitoring is impractical in most workplace situations these indicators can still be used to some extent to determine the workers suitability to commence work in a thermal stress situation, evaluate workers experiencing symptoms possibly related to thermal strain, or to monitor recovery from thermal strain situations. Consideration should be given to engaging nursing personal, or training paramedics, or health and safety staff to measure and monitor heart rate (palpation), core temperature (Tympanic Membrane temperature monitors), and hydration (urine specific gravity testing).

- Environmental Risk Assessment: These should be undertaken on the working environment to determine areas of high heat stress due to workplace factors such as proximity to heat generating equipment, areas of poor or variable ventilation and areas of increased humidity.

- Work Practices & Procedure Risk Assessment: These are necessary to determine jobs requiring high physical output, which could be, expected to generate significant levels of metabolic heat.

- Worker Risk Assessment: To identify workers with increased risk of experiencing heat strain due to individual health factors such as physical fitness, obesity, chronic illness, and use of medication and other drugs. A supplementary form of medical risk assessment should also be available to identify people with temporary changes in their health status due to intercurrent illness, psychological distress, or other factors leading to temporary loss of acclimatisation such as absence from the environment. Some form of initial assessment is required to identifying unacclimatised new employees or visitors, particularly if from colder environments.

- Consider determining and prioritising levels of risk based on hazardous exposures associated with; duration of exposure, exposure to adverse heat stress conditions (eg. high humidity, variable air velocity resulting in thermal loading), or jobs requiring high physical demand where high metabolic heat reduction could be anticipated. Workers could then be categorised as being suitable (or temporarily or permanently unsuitable) to work in these particular hazardous levels on the basis of their; health, physical fitness, and acclimatisation.

- Implement an acclimatisation regime for at risk workers undertaking high risk jobs.
- Implement an awareness program for the workforce to educate them about the risks, personal management of working in heat, identification of symptoms and signs of heat strain, and first aid treatment. This should include some form of formal advise and training, provision of literature, discussion in toolbox talks, and initially at least, pre and post-shift screening of workers for dehydration. The provision of some or all of these elements could be based on the levels of risk, and incorporated into the induction process.
- Implement a training program for managers, supervisors and health and safety personnel to cover the above aspects as well as the primary and secondary management of heat stressed workers, and acclimatisation management.

Any development of policies and procedures to assist in the effective management of thermal stress and limit thermal strain should incorporate comprehensive risk identification, assessment, and controls of the workplace, processes, practices and procedures, as well as individual workers. Simply relying on prescriptive regulation or generic management processes cannot be expected to deliver efficient or cost effective systems.

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APPENDIX A

Mr P

Personal Details	Age 46 yrs, Boilermaker, Residence Coastal Central Queensland (Lat 22° S).
Workplace / Process	Underground development work, Metalliferous Mine YY, fly in fly out, North West Qld, (Lat 19° S), Commenced work - 3/1/99
Work Practices	Contract Welding / steel fabrication, Roster: 12 hr rotating shifts, 7 on, 4 off
Situation	Found dead while welding underground, wearing a boiler suit, 90 mins into day shift 5/1/99
Work History	Past Employment – Contract Construction and Steel Fabrication work Last employment – Construction worker (contract), Southern Australia, 2 weeks, Development Mine XX, (Lat 33° S).
Worker	Pre-employment medical performed Dr S (Mine XX)- 9/12/98, Assessed suitable Dr A Significant Findings: Nil of note in medical history, B P 150/88, BMI - 28.19 (20 - 25), Urine Glucose ++ Medical Mine XX accepted by contractor Mine YY
Post Mortem Findings	Blood Alcohol Level 0.02, No other relevant findings detected.

Significant Points	Hot Climate Hot Work, Clothing - insulation factor = 0.55 cf lightweight short sleeve shirt and trousers = 0.35 Unacclimatised Festive season, alcohol, sleep deprivation Offsite medical adviser assessed suitable for large development site with on site nursing and medical cover. Mildly overweight, Borderline hypertension, undiagnosed diabetic - advised by doctor performing medical to see GP about,
Probable Cause of Death	Cardiac Arrhythmia - Probably resulting from dehydration with electrolyte imbalance secondary to Heat strain, contributing factors - diabetes, alcohol, ? missed pre-shift meal.