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HEALTH & SAFETY LABORATORY

Dehydration Review

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Contents

Summary

Objectives

The main objective of this study was to systematically review the current knowledge on dehydration. Specific to this objective a number of areas were investigated, including:

- Causal factors in dehydration
- Limiting effects on human cognitive and physiological performance
- Health effects of cumulative dehydration

From this review, advice for working safely in hot and cold industries where dehydration may be an underlying problem or risk has been developed. The following points were considered to be important in deriving this information:

1. Provision of a formal definition of dehydration
2. Identification and description of measures of dehydration
3. Description of medical conditions that may exacerbate dehydration
4. Provisional advice on acclimatisation and re-hydration procedures

Main Findings

1. Dehydration in work places is an important issue that is not always taken seriously, or underestimated by employers as a part of work ethics. The workers are left to deal with dehydration by treating it as a normal thirst and therefore allowed to take liquid as and when they feel it is necessary. The awareness of physiological and health consequences of dehydration should be of paramount importance for the safety of the workers. In an industry with a heat stress problem, there ideally should be a facility for health screening prior to employment as pre-existing medical conditions combined with dehydration have the potential to be fatal.

Main Recommendations

1. A guideline to describe warning signs of dehydration and likely scenarios where dehydration may occur should be established.
2. Recommendations for avoiding dehydration in industry should be compiled and distributed to industry at the ‘shop floor’ level.
3. Remedial action to be taken in the event of dehydration should be considered and this information made available at all levels of industry.

1 Glossary of Terms

Acclimatised	Body's adaptation to new environments
Aerobic capacity	Capacity to transfer oxygen to blood
Anthropometric	The measurements of height, weight, fat content, age etc. of a person
Anuria	Absence of urination
Cardiac output	The amount of blood pumped out by the ventricles in a given period of time
Cardiovascular	Relating to heart and blood supply
Circulatory collapse	Failing to pump blood around the body adequately
Cognitive	Performance of mental functions
Core temperature	The internal temperature of the organs and brain
Electrolytes	Salts such as potassium chloride
Euhydrated	Replacement of water to maintain body fluid
Extravasation	To force the flow of (blood or lymph) from a vessel out into surrounding tissue.
Haemorrhaging	Internal bleeding
Hidromeiosis	Reduction in of sweating associated with wetting the skin (either in hot humid conditions or in water)
Hematocrit level	The percentage by volume of packed red blood cells in a given sample of blood after centrifugation
Hypertension	High blood pressure
Hyperthermia	High internal body temperature
Hyperventilate	Faster breathing
Hypohydration	Less than normal water content of the body
Hyponatremia	Low concentration of sodium in the blood
Innervation	Nerve supply to the particular site
NBC clothing	Nuclear, biological and chemical protective clothing
Oligurai	Decreased amount of urination
Osmolality	Capacity of liquid transfer within cell compartments
Plasma volume	Total blood and serum volume
Prophylactic	Acting to defend against or prevent something, especially disease; protective
Renal failure	Dysfunctional kidney
Sodium chloride	Common salt
Stroke volume	Amount of blood pumped in one stroke of heart
Tachycardia	Faster beating of the heart
Thermoreceptor	Sensors that detect temperature change
Thermoregulate	To control the inner body temperature
TT	Heat tolerance time
Vasodilation	Widening of blood vessels
Venous blood	Returning blood to the heart

2 Introduction

Humans interact with their thermal environment, through a combination of physiological and psychological adaptations to thermal stressors. These adaptations occur in order to maintain deep body temperature at or about 37°C. Deep body temperature is known as "core temperature" and describes the temperature of the internal organs and the brain. To achieve this thermal equilibrium, there must be a balance between the amount of heat generated within the body and the heat transferred to or from it. When an increase in body temperature occurs, blood flow to the skin increases through the dilation of the blood vessels beneath the skin. This encourages the movement of heat from the blood, through the skin to the environment. This reduces the temperature of the blood returning to the heart and lungs, where it is re-heated and the process is continued to maintain core temperature.

The dominant driving force in achieving and maintaining thermal equilibrium in hot environments is the evaporation of sweat. An example of the capacity for heat loss through sweat evaporation is provided by Maughan and Noakes (1991). They state that the evaporation of 1 litre of water dissipates 580 kcal of heat from the body. Prolonged or profuse sweating leads to the loss of both water and electrolytes (salts), which, unless replaced, leads to dehydration and heat, related illnesses. During sweating, salt is lost at about 4 g per litre in unacclimatised workers and 1 g per litre in acclimatised workers.

As deep body temperature rises, so the rate at which people sweat increases. The rate of sweating increases 10-20 fold when deep body temperature increases by 1°C, compared to the same increase in mean skin temperature (Wissler, 1988). In humid environments the increased vapour pressure reduces the ability for sweat to evaporate. The dripping of sweat may occur in this situation, resulting in a reduction in the effectiveness of heat loss because less sweat is evaporated. This leads to an increase in the amount of sweat on the skin. A decrease in sweating may occur as a result of the deep body temperature continuing to rise and the skin becoming wetted with unevaporated sweat.

Due to vasodilation of the blood vessels in the skin, less blood is returned to the deep body (NIOSH, 1986). This results in an increased heart rate to maintain the same cardiac output. Consequently, heart rate increases during heat stress compared to the same work rate in neutral conditions. Severe dehydration also affects cardiac output by decreasing the volume of circulating blood (Rodahl and Guthe, 1988). This, in turn, reduces the blood flow to the skin and muscles. The body's capacity for heat endurance is compromised because heat dissipation is attenuated as less blood reaches the skin (Nielsen and Kacuiba-Uscilko, 2001). Rectal temperature, which is used as an indication of core temperature, is always significantly higher in dehydrated subjects. Further dehydration and increased hyperthermia may eventually result in a reduction of central venous pressure and circulatory collapse.

Thus, the hydration status of the worker is pivotal to their ability to thermoregulate and for their well being when working in hot environments. This report describes a literature review of dehydration to provide HSE with guidance on reducing the risk of dehydration in industry. Information will also be provided on appropriate re-hydration strategies that may be employed.

3 Thermoregulation and the Importance of Homeostasis

3.1 Definitions

The following provides a brief description of thermoregulation, homeostasis, dehydration and associated terminology.

Two terms, which will be discussed throughout this report, are dehydration and hypohydration. These two phrases are not interchangeable. They are different conditions and should therefore be treated as such. The dynamic loss of water from the body due to sweating without fluid replacement, or where fluid replacement does not match the rate at which fluid is lost, defines dehydration. Hypohydration on the other hand, refers to the hydration state of the body after a certain amount of body water has been lost. Hypohydration is therefore the consequence of dehydration.

In order to understand how humans thermoregulate, it is necessary to first describe how the process starts and why it starts. The consequences of excessive sweat loss resulting in dehydration will also be explored.

3.2 Temperature sensitive neurons

In the hypothalamus, temperature sensitive "proeptic and anterior hypothalamus" (PO/AH) neurons respond to changes both in their temperature (i.e. in the brain), and to the temperature changes elsewhere in the body. This shows that PO/AH neurons can compare and integrate thermal information from both the central and peripheral systems of the body. It is this integration of system inputs from and around the body that enables the PO/AH to control a variety of autonomic and behavioural thermoregulatory responses. For effective thermoregulation to occur, it is vital that these responses are appropriate and take into account both internal and external environmental conditions.

Dehydration plays an important part in the ability of the PO/AH thermosensitive neurons to function as they are affected by plasma osmolality (e.g. this may change during dehydration) and glucose concentration. Interestingly though, increases in temperature also affect many of the non-thermoregulatory systems; suppressing feeding drives and increasing water retention. Therefore, the PO/AH neurons play a role not only in thermoregulation but also in the regulation of a variety of homeostatic systems (Buoyant, 2001; Nielsen and Kacuiba-Uscilko, 2001).

3.3 The mechanisms involved in heat balance

The mechanisms involved in maintaining a steady thermal state are represented in Table 1. When this balance is not achieved, the body is either gaining heat or loosing heat. If the body gains heat, there is a possibility of heat stress and if the intake of water is not adequate then the process of 'dehydration' will start.

Table 1: Description of mechanisms for achieving steady state (thermoregulation) through heat loss and heat gain (adapted from Werner, 2001)

STEADY STATE (Heat Balance)	
Heat gain	**Heat loss**
Basal heat production	Evaporation of Sweat
Heat production by exercise	Respiratory evaporation
Shivering	Decrease of insulation
Conduction/Convection	Conduction/Convection
Radiation	Radiation

The dominant driving force in achieving and maintaining thermal equilibrium in hot environments is through the evaporation of sweat.

3.4 Homeostasis

The mean water content of a human body is usually in the range of 50% to 70% with a mean of 61%. The total content of water in the body of an average man (weight 70 kg) is approximately 40 litres; which is about 57% of his total body weight. The total water content of the body is dependent on the balance between the daily intake of fluids and amount of water lost. Most of our daily water intake (90%) is gained orally, from drinking water and other beverages. A small amount is gained from food intake. The normal fluid intake average is about 2.3 litres per day (Costil, 1972). On the other hand, the daily loss of water from the body is highly dependent on the environment. For example, at an air temperature of 20°C, the average water loss is about:

- 1.3 litres in urine;
- 0.1 litres in sweat;
- 0.1 litres in faeces;
- 0.7 litres by evaporation from the respiratory tract and diffusion through the skin.

In a hot working environment, water loss by sweating can increase to as much as 3.5 litres an hour (Guyton, 1981, Armstrong, *et al*, 1986). This can rapidly deplete body fluid. In addition, exercise and physical exertion can also increase water loss in two ways:

1.) **Increased rate of respiration.** Large amounts of water can be lost through this route.

2.) **Exercise or physical work.** To regulate core temperature, sweating may result in excessive loss of body fluid.

For moderate workloads, the typical sweat rate is 1 litre per hour (Cheung *et al*, 2000), although Armstrong et al (1986) recorded a maximum level of 3.7 litres (for an Olympic Marathon athlete). When the body attains these sweating levels the risk of excessive dehydration is imminent. If a re-hydration protocol is in place and a palatable liquid is available then the risk of dehydration can be reduced. It is well documented that the rate of *ad libitum* fluid intake rarely matches the rate at which water is lost; even when an adequate water supply is available (Armstrong et al, 1985; Greenleaf, 1992).

Voluntary dehydration has a behavioural component, where personal preferences (e.g. palpability and water temperature) or the availability of drinking water may be causal factors in dehydration.

4 Sweating and Sweat Rates

4.1 The Biochemistry and Physiology of Sweating

A rise in core temperature acts as the main signal to control skin vasodilation and sweating. Hormones and metabolites that are released into the blood in response to exercise also initiate sweating. Thermoregulatory sweat in humans is controlled by the eccrine sweat glands. These cover the hairless surface area of the body and number between 2 to 5 million. The sweat glands are tubular structures with a deep sub-dermal coiled portion and a duct portion. The coiled part of the gland secretes the sweat, and the duct portion directs the sweat towards the dermal and epidermal layers of the skin.

Several neurological pathways control the regulation of sweating. The eccrine sweat glands consist of α and β adrenergic receptors. Sympathetic cholinergic stimulation is responsible for the response of the eccrine sweat glands to thermal stress. The sweat glands in the hands and feet have adrenergic and cholinergic innervation. During exercise, the adrenergic pathways are activated, which produces localised sweating in the hands and feet. Moisture from sweat helps prevent drying of the thick cornified layers of the skin. Emotional responses can also trigger the adrenergic nerves initiating sweating.

Circulating epinephrine and/or norepinephrine also initiates sweating from sweat glands that are not innervated. The hypothalamic and proeptic neurones are affected by pyrogens, which induce a fever response by activating heat retention and heat production responses. These neurones can sense changes in core temperature and integrate information from the central and peripheral thermal sensors of the body. This can also initiate sweating (Guyton, 1981).

Water lost by the body, except respiratory water loss, always contains electrolytes. These electrolytes consist mainly of sodium (Na^+) and chloride (Cl^-) ions (which comprise about 80% of the osmatically active particles in the extracellular fluid). By contrast, the intracellular fluid electrolytes, (potassium K^+, magnesium Mg^{2+}, hydrogen phosphateHPO_4^{2-} ions) are found in greater quantities in urine but in small quantities in plasma and sweat (Armstrong *et al*, 1987). Sweat is usually hypotonic and as such, an increase in the osmotic pressure of extracellular fluids accompanies sweat loss as the electrolytes become more concentrated in the body. When the rate of sweating is low, the sodium chloride (NaCl) concentration in the sweat is also low. This is because the tubular part of the gland reabsorbs the NaCl before it reaches the skin. However, when sweating is profuse the reabsorption of these electrolytes does not match the rate of sweating. In other words, the electrolytes are lost at a rate faster than they can be reabsorbed.

The normal level of NaCl for an adult in sweat ranges between 20-120 mm/litre (Morimoto, 2001). In unacclimatised individuals the concentration of NaCl in sweat usually rises to over 120 mm/litre for. However, there is an increased Na^+ reabsorption rate in acclimatised subjects, and as such less NaCl is lost by acclimatised than unacclimatised subjects. The concentrations of these electrolytes during profuse sweating are low. Thus, the only electrolyte affected by sweating is

NaCl, which is important for many of the cellular functions of the body. Since large amounts of NaCl are lost during profuse sweating, it is important to manage excessive sweating before dehydration sets in.

Acclimatised subjects can achieve sweat rates in excess of 2 l/h, which, if all the sweat were evaporated from the skin, would be equivalent to 4860 kJ or 1161 kcal of heat loss (Morimoto, 2001). Along with increasing sweat rate, acclimation can progressively reduce the concentration of NaCl in the sweat, to avoid salt depletion. Most of this effect is caused by an increase in the secretion of the hormone aldosterone. An unacclimatised person can loose 15 - 30 grams of salt per day, which after acclimatisation can be reduced to 3-5 grams a day. Acclimation however, should not be considered in isolation (Hubbard and Armstrong, 1988). Other considerations such as dietary salt intake, water intake etc should also be explored.

4.2 The evaporation of sweat

Heat exchange from the body to the environment is mainly related to the evaporative capacity of sweating. As a person sweats, their skin becomes more wetted with unevaporated sweat. This is known as skin wettedness. In general though, the core temperature, skin temperature, skin wettedness, metabolic rate, clothing, fitness, gender and hydration state of the individual will determine the sweat rate. The environmental conditions, skin wettedness and clothing influence the rate at which sweat evaporates.

Skin wettedness has an impact therefore, on both sweat rate and evaporation rate. Sweat rate may decrease over time if high skin wettedness is present due to the build up of sweat on the skin resulting in a build up of salts clogging the sweat pores. Clinically this is known as a sweat rash.

The evaporative capacity and the wettedness of the skin are directly dependent upon atmospheric humidity. The higher the humidity, the smaller the vapour pressure difference between the wetted skin and the atmosphere. This will result in less sweat evaporation. This is important because heat loss through the dripping of sweat is negligible. Candas *et al* (1983) reported that sweat evaporative efficiency seriously decreases significantly and (sweat becomes ineffective for body cooling purposes) when skin wettedness reaches levels greater than 60 to 70% depending upon acclimation and environmental condition. So the possibility of dehydration is higher in hot-humid conditions than in hot-dry conditions.

5 Dehydration

5.1 The Physiological cost of dehydration

The overall effect of dehydration is water deficit. However this does not occur alone. Dehydration leads to electrolyte imbalance, which affects the normal functioning of the nervous system, heart and kidneys. As a result of dehydration, mental confusion, hallucinations, seizures, renal damage, coma and eventually cardiovascular collapse and death may occur.

There are two types of dehydration these are:

- Hyponatraemic dehydration, which occurs as a result of excess loss of water through trauma, burns, surgical intervention, severe vomiting or diarrhoea.
- Hypernatraemic dehydration, which occurs as a result of a reduction in water intake to the point where it is less than that that is required to maintain balance.

It is hypernatraemic dehydration that will be considered in this review.

Typical water loss rates under normal environments during the course of a day (Guyton, 1981) are:

1. Respiration - 1 to 2 litres from the lungs (via normal breathing)
2. Perspiration - Sweat (8-10 litres over half a day after exercise)
3. Urination - 1 to 2 litre daily
4. Defecation - 0.1 litres daily (illness can cause to loss up to 25 litres)

Since the regulation of body temperature has priority over the regulation of body water, dehydration may be a real threat to the well being of workers in hot environments. The risk of dehydration increases dramatically if the water that is lost is not adequately replenished.

As discussed previously, when body temperature rises less blood is returned to the deep body due to the vasodilation of the blood vessels in the skin. Thermoregulatory requirements, thus override the cardiovascular requirements. Hence, the thermally induced increase in heart rate known as "*thermal drift*" or "*cardiac beats*". This is important as dehydration also has an effect on heart rate. Prolonged exercise and/or exposure to heat almost always causes hypohydration (chronic lowering of total body water). This results in a lowered volume of circulating blood (Rodahl and Guthe, 1988) leading to a decrease in the plasma volume and an increase in the protein content of the blood. This causes the shrinkage of erythrocytes as a result of osmolality. Furthermore, cardiac output and blood pressure also decrease. As a result, blood flow to the skin and muscles is reduced and the capacity for effective heat loss from the deep body is reduced. If no action is taken with the initial onset of dehydration, the final outcome will be an increase in core temperature. Deep body temperature has been shown to always be higher in dehydrated subjects when compared to those subjects who are euhydrated (Cheung and McLellan, 1998).

Costill and Fink (1974) reported a study that they conducted on healthy volunteers following dehydration (4% of the body weight) by exposure to the following conditions:

- Hot and dry environments (Thermal dehydration, Th)
- Prolonged exercise for 2 hours (exercise dehydration, Ex)

Venous blood was collected after 15, 30, 60, 90, 120 and 180 minutes. Rectal temperature and plasma volume were measured throughout the duration of the experiment. Following dehydration, at the 30-minute collection point, plasma volume increased by approximately 7 %. At the same time rectal temperature decreased. It was suggested that the reduction of rectal temperature was due to water entering the dermal tissue as a result of peripheral vasodilation. At the same time, plasma volume also recovered due to re-entering of sweat during the recovery period. The plasma volume remained stable from 30 minutes to 180 minutes. However, the overall reduction of plasma volume was 9% less than the pre-dehydrated volume. Regardless of the method of dehydration (i.e. Ex or Th), the reduction in plasma volume was similar (9 % decrease) in both cases. However, there were definite changes in plasma total protein and plasma potassium values between the two methods of dehydration and pre and post-dehydration status. It was also found that plasma protein loss after dehydration was minimal compared to the huge changes in plasma volume levels. Their conclusion was that some of the plasma protein might have re-entered the plasma both during and after the first 30 minutes recovery period.

Sawka et al (1992) investigated the influence of hydration under heat stress conditions (where the required evaporation rate exceeded the maximum evaporation rate possible – i.e. heat gain would occur). They compared the tolerance of euhydrated and hypohydrated (by 8% of total body water content) participants to heat strain. It was determined that hypohydrated subjects tolerated a lower core temperature. However, the benefits usually associated with increased physical fitness were not evident, as the state of hydration appeared to override any of these benefits. Exhaustion was rarely found at core temperatures below 38°C. Blood plasma volume and body weight showed significant decreases due to hypohydration, while plasma osmolality showed a significant increase. Further exercise decreased plasma volume and plasma osmolality. Both hypohydration and exercise also increased blood lactate with the largest increased being found during exercise when hypohydrated. Sweat rates were also found to be lower in hypohydrated participants, while heart rates at exhaustion were lower in the euhydrated participants. It is important to note though, that the core temperature limits reached were higher than those applicable to industry.

Other studies explained the rapid shift in blood volume, which can occur during exercise and heat exposure, as the result of fluid leaving the vascular system rather than entering cells (Lundvall, 1972).

Gonzalez-Alonso *et al* (2000) demonstrated the importance of hydration state on the ability to thermoregulate. They studied the physiological responses of euhydrated and dehydrated participants exercising in both hot and cold conditions, where:

(1) Cold condition
   - dry bulb temperature, 8.2°C;
   - relative humidity, 7 5 % and;
   - air velocity, 2m/s

(2) Hot condition

- dry bulb temperature, 35.4°C;
- relative humidity, 47 % and;
- air velocity 2m/s

The group were dehydrated by 1.5 %, 3 % or 4.2 % of their body weight. It was established that core temperatures (oesophageal) and stroke volumes of euhydrated subjects were similar between the hot and the cold environment, although skin blood flow was much higher in the hot condition. This was in contrast to the dehydrated participants whom for every 1 % of body weight lost, significantly increased their core temperature in the hot environment when compared to the cold environment. They also found that stroke volume decreased by about 4.8 % in the hot environment, and by 2.5 % in the cold. Therefore the reductions in the stroke volume were not associated with the increases in skin blood flow. This is explained by the fact that the euhydrated participants showed little change in stroke volume, while exhibiting a significant change in skin blood flow in the hot condition. These results suggested that in physically fit participants, the stroke volume was maintained when they were euhydrated irrespective of the thermal environment. When these participants were dehydrated the stroke volume decreased significantly. Therefore they concluded that the decrease in stroke volume was associated with the hydration state rather than skin blood flow (i.e. in response to thermoregulatory needs).

A further consequence of the reduction in blood volume due to hypohydration is that the reduced cardiac output may result in an insufficient supply of cool blood to the brain. Even in healthy workers, this can manifest itself in heat exhaustion or collapse, (Rodahl and Guthe, 1988).

5.2 Measurement of dehydration

There are different procedures that are adapted to measure the hydration status of the body. The one most commonly used, involves the participant's height, body weight, percentage body fat, and predicted maximal O_2 uptake being measured. (American College of Sport Medicine Guidelines 1991). To assess the exact rate of dehydration, aural temperature, 4-point mean skin temperature, heart rate, body weight loss (% total body weight lost) must be recorded continuously throughout the experiment or observation. Samples of blood, urine and sweat may also be collected to determine the level of hydration status. Urine osmolality, urine specific gravity (Adolph, 1947, Armstrong *et al.,* 1994, Francesconi, *et al*., 1987) and blood plasma volume at the beginning and at the end of the heat exposure should also be measured. Sweat samples can also be collected from sweat patches from several sites (n=7) and then analysed for sodium and potassium concentration. Blood samples are to be analysed for haemoglobin, Haematocrit, and change in plasma volume. Stirling and Parsons (1998) recommended that the following parameters should be measured from a urine sample as a measure of dehydration: osmolality, specific gravity, colour, volume, temperature, pH, sodium and potassium levels. Stirling and Parsons concluded that the changes in hydration status was not reflected accurately in haematological indices as the body actively attempted to preserve plasma volume by moving fluids from the intracellular to extracellular spaces. However there was a strong correlation between hydration status and urine osmolality (U_{osm}) and urine specific gravity (U_k)

measurements. In their study the urine colour (U_{col}) also indicated the degree of dehydration. Their conclusion was that U_{col} could be used as a marker for dehydration if detailed physiological measurement were either not available or practically impossible to do. The only cautionary note is the diet of the participant prior to analysis as carrot and beetroot can interfere with the colour of the urine.

In this study they have also observed that urinary and physiological variables are still affected by heat exposure and exercise, even after re-hydration. The urine samples collected after 6 hours of exposure, exhibited signs of dehydration in that the values of U_{osm}, U_k and U_{col} were significantly elevated suggesting that the water conservation mechanisms of the body were still in place. In some cases sweat rate was so high (0.85 litre per hour) that the volume of water or liquid to replace this magnitude of dehydration was too large and practically not possible to consume.

These findings suggested that, to completely recover from heat stress and dehydration the ‘Re-hydration Procedure should last several hours after exposure ceases.

5.3 Estimating Total Sweat Loss

The difference between the body mass measured prior to a specified time period and that at the end of a time period will provide the gross body mass loss (mg) of a person during that period.

The calculation, correcting the weights of any fluid and/or food intake and urine and/or faeces excretion can be written as:

SWtot = (Weight Before + Fluid + Food) - (Weight After + Urine + Faeces)

It is recommended that the scales used to measure human weight have a precision of less than 50 g, while those used to measure the masses of ingestion and excretions should have a precision that is better than 20 g.

6 Effects of Dehydration on Human Performance

6.1 Physiological tolerance to heat strain during exercise

Quantifying the effects of dehydration and hydration status from an industrial health and safety perspective is crucial as it establishes occupational safety limits for dehydration.

6.2 Health Effects

The immediate sign of dehydration is the lack of urination or small volume of concentrated yellow urine.

The other clinical symptoms associated with dehydration are:

- Dizziness
- Fatigue and Malaise
- Flushed face and Sunken eyes
- Dry and sticky mucus membranes in the mouth
- Oligurai (decreased) or Anuria (absence) of urine

Chronic symptoms include:

- Constipation
- Kidney stone
- Urinary tract infection

Severe cases of dehydration can result in:

- Abdominal cramps
- Vomiting
- Convulsion
- Confusion
- Comas
- Cardiac failure
- Death

Severe cases of dehydration can lead to heart attack, hypertension, haemorrhage or acute renal failure. In the case of severe dehydration death can occur (Weil and Afifi, 1970).

There is also a tentative link between dehydration and bladder cancer in men. Michaud et al (1999) determined that an increase in total fluid intake reduced the contact time between carcinogens and the urothelium by dilution of urinary metabolites and an increased frequency of voiding.

6.3 Cardiac Effects of Dehydration

Horstman et al (1973) demonstrated that in dehydrated people undergoing moderate heat stress cardiac output increases two fold and remains at that level during a dehydration period of seven hours. They also determined, that ventilatory volumes, oxygen uptake, cardiac output, heart rate and stroke volume were all significantly higher and arterial-venous oxygen differences were significantly less during dehydration exposure than under control conditions. The increase in heart rate demonstrates the heart working harder under dehydrated conditions than in hydrated conditions to circulate a decreased volume of blood (as evidenced by the increased stroke rate and decreased stroke volume). This can put an intolerable strain on the cardiovascular system eventually resulting in cardiovascular collapse.

6.4 Salt depletion dehydration

When individuals are exposed to regular heat stress and fail to take proper precautions 'salt depletion dehydration' may occur. This phenomenon has been described by Goldman (1988). Salt depletion dehydration is a serious condition although it is relatively uncommon. In this condition the body adapts to a new low salt and water balance. The body does not recognise the lower electrolyte levels and lack of fluid so it doesn't try to correct the problem. As a consequence, after the dehydration sets in, the body may not absorb the extra salt and fluid being taken orally. According to Goldman the intake of salt and water must be set up from the beginning of the work to avoid this condition.

6.5 Over breathing

In hot and humid conditions some individuals may have a tendency to pant. This is another way of getting rid of excessive heat. By doing this the person may 'hyperventilate' to get rid of excessive carbon dioxide in the blood. As a result the person may become blue, have tingling sensations in the lips, may feel dizzy and eventually collapse. Some of the muscles in the hand may be stiff due to muscle cramp. At the same time the person will dehydrate due to heavy respiration.
To recover from this situation, drinking a small amount of water and deep and slow breathing is recommended to adjust the blood CO_2 level (Goldman 1988).

6.6 Dehydration under compressed air

It is well known that the ability of an individual to tolerate heat strain may depend on the state of dehydration. Dehydration increases cardiovascular strain by reducing stroke volume (Costill and Fink, 1974) and increases core temperature (Sawka and Pandolf, 1990).

The situation is further exacerbated in compressed air environments, where dehydration seems to affect adequate decompression (Luther *et al*, 1994). In a dehydration study of miners by Kampmann *et al*, (1988) it was observed that over several shifts miners showed a significant level of dehydration, even when the effects of water loss over one shift was not significant. The rate of dehydration in miners was dependent on the level of climatic stress and the degree of physical work they have to endure during the shift. This has obvious implications for miners and compressed air tunnellers.

6.7 Cognitive effect due to dehydration

The effect of dehydration on the cognitive ability of a person has been well studied (Pepler, 1958). However, the size of the effect depends on the level of radiant heat, duration of exposure, relative humidity and heat acclimatisation status. Sharma *et al*, (1986) have studied the mental functions and performances of young, male individuals with dehydration levels of 1 %, 2 % and 3 % of their body weight. The participants were acclimatised for eight consecutive days in a 45°C dry bulb and relative humidity of 30% environment whilst conducting moderate work. The individuals were then exposed to a heat stress condition in a climatic chamber in “hot-dry” (DB at 45°C and RH at 30 %) and to a “dry-humid” condition (DB 39°C, RH 60 %). They were dehydrated to the maximal level of 3 % of their body weight then psychological tests were conducted. The conclusion from the study was that at 1% or less dehydration state has relatively little effect on coordination functions. However, at higher dehydration levels all cognitive functions are decreased. A second study (Gopinathan et al, 1988) confirmed that, at 2% or more loss of body mass through dehydration, there is significant deterioration in mental function.

6.8 Other medical considerations of dehydration

Dehydration can affect all organs. Heat stress and dehydration in its acute form may lead to renal failure even in a healthy person as described in a young female traveller (Pattison et *al*, 1988). People with allergies and/or skin conditions, e.g. psoriatic patients, are also at risk from heat stress and may be more vulnerable to dehydration (Leibowitz *et al*, 1991).

Medications or drugs that may affect heat tolerance include:

Anti-cholinergic drugs including:

- Lomotil,
- Phenothiazine,
- Those present in cold remedies as they are also known to impede sweating

Diuretics (lead to depletion of water and salt) including:

- Frusemide,
- Amiloride
- Caffeine (e.g. present in tea, coffee, coke etc)
- Alcohol (4% alcohol will delay fluid restoration (Sheriffs and Maughan, 1997))

Tricyclic antidepressants (impair concentration and increase motor activity and therefore heat production. Dehydration is also a rare side effect of these drugs). Examples include:

- Amitryptilline,
- Prozac

Beta blockers (may increase risk by reducing cardiovascular responses) examples include:

- Atenolol,
- Propanol

Analgesics (may cause a decrease in renal flow when dehydrated) examples include:

- Ibuprofen
- Actaminophen

Aggravating factors for dehydration:

- Dehydration illness
- Diarrhoea
- Vomiting
- Failure to replace fluid loss

6.9 Hidromeiosis

Hidromeiosis is a clinical condition described as a decrease in the rate of thermally induced sweating. The homeothermic mechanism of the body reduces body temperature by the evaporation of sweat produced by the eccrine glands. The eccrine sweat glands are stimulated by the cholinergic sympathetic neurons that are in turn stimulated by the thermoreceptors. These glands can also be stimulated centrally by the hypothalamus. After attaining the initial maximal rate in a hot environment, the sweat rate declines and Hidromeiosis may occur (Brown and Sargent, 1965).

Several factors may influence Hidromeiosis including:

Dehydration – this may accelerate the process of Hidromeiosis
The duration of thermal exposure rather than the intensity of the work

However, the acclimation process does not affect Hidromeiosis.

Hidromeiosis may be the cause of sweat gland fatigue. It is possibly for this reason that the process is irreversible. However some scientists disagree with this. Bernard and Sargent have quoted the observation of Randell and Peiss (1957), that *"drying wetted skin will lead to restoration of sweating"*. Moreover the restoration of sweating does not stop the increase in rectal temperature. Candas *et al*, (1983) have also studied Hidromeiosis in detail and concluded that there are three stages of hidromeiosis. During the first stage of heat exposure the rate of sweating increases. In the second phase with acclimation, sweat rate decreases with increasing skin wettedness and dripping. Finally hidromeiosis sets in with decreased dripping of sweat.

This mechanism of hidromeiosis is beneficial to an individual who is already dehydrated. This is an indirect way of saving inefficient water loss. It is therefore possible, that hidromeiosis is a type of regulatory feed back mechanism rather then simply a result of non-functional sweat glands.

6.10 Sweat Gland fatigue

Sweat gland fatigue may occur after severe sweating, when the sweat glands become inefficient due to overdrive of its cellular mechanism. This condition is often mistaken for hidromeiosis.

7 Physical Ability to Tolerate Dehydration

Sweating responses vary between individuals and are also dependent on the age, gender, physical fitness, state of acclimation and health status of an individual. Each of these aspects is discussed briefly in turn.

7.1 The benefits of acclimation

The benefits of heat acclimation are widely published in literature and are recognised as a significant control option for reducing the risk of heat stress in industry. The process of acclimation in people living in cooler climates (e.g. Northern Europe) produces what could be viewed as capitulation or regression in the evolutionary process of humans. Essentially a number of global responses in the human body are observed, including; "*lowered internal body temperature, decreased metabolic rate (heat production), lowered heart rate, elevated stroke volume, augmented thermoregulatory skin blood flow, and increased capacity of the evaporative cooling system*" (Horowitz, 2001.) It is estimated that these physiological adaptations may result in an increased heat endurance capability of about 60 to 70%. It is important to note however, this increase is a best-case scenario because the level of acclimation and the magnitude of these global changes greatly vary due to differences in acclimation processes. Variations in heating protocols, activity levels, duration of each exposure and number of exposures for example can all have an affect on the level of acclimation achieved.

It is generally accepted that heat acclimation increases the sweating response. This is due to both an increase in the sweat secretion capacity of the sweat glands and the adaptive changes of the central thermoregulatory mechanisms (Fox *et al*, 1964).

An example of this was illustrated when reviewing the literature. Horowitz, found that some authors reported an expansion of blood plasma volume following acclimation, while others did not. There does appear however to be strong evidence to support the basis for plasma volume expansion following acclimation which comes about as a result of an increase in the protein mass in the plasma compartment. Osmotic power for the shift/retention of water from/to the compartment is thus provided. This process is supported by the increase in plasma protein synthesis and an accelerated return of the proteins along the lymphatic pathways. In terms of water loss, these changes are rather significant. Acclimation to heat is lost once repeated exposures to heat is stopped or interrupted.

7.2 Core Temperature and Dehydration

Studies have shown that the core temperature may provide the best physiological parameter for indicating heat stress (Rodahl and Guthe, 1988) though it is slow to respond to heat increase. However, McLellan et al (1999) have stated that there was considerable individual variation in the upper limit of rectal or core temperature for the tolerance of heat. The upper limit of rectal temperature is within the range of 38°C to 39.7°C. The main impact on work performance is the dehydration status of the individual. If a person is adequately euhydrated, they can tolerate higher rectal temperature before being affected by heat stress.

7.3 Effects of age on dehydration tolerance and heat stress

It is well published that in response to a raised body temperature and increased humoral signals, sweating responses in people over the age of 65 years may be reduced. It is generally accepted that older workers (45 to 64 years of age) have lower tolerances for working in hot climatic conditions and that their acclimatisation to heat causes higher physiological strain than that found in younger workers (Hellon & Lind, 1958; Lind *et al*, 1970). Marszalek *et al* (1999) observed that in an older subject group, the rectal temperature, mean skin temperature and heat storage increased significantly after exercise in an environment with a wet bulb globe temperature (*WBGT)* of 29°C compared to younger workers.

A further study by Marszalek (2000) observed that older people had a lower thirst drive and had lower re-hydration rates when compared to their younger counterparts. It was also observed that during relatively short exposures to heat with and without radiation and protective clothing (WBGT around 29°C) older men (58-65) seem not to be at a greater risk for excessive heat strain than young (20-28) and middle-aged men (42-52). However in a hot environment dehydration is a potential risk factor for older workers. In addition, reduced thirst in older men may cause a reduction in plasma volume (Kenny, 1988) and a decrease in skin blood flow (Fortney, *et al*, 1984). Consequently, this may put the older group in a higher risk category to suffer from dehydration. Thus, special attention should be paid to the importance of fluid replacement in older people in hot work places.

It is important however, not to consider the limiting criteria for dehydration tolerance on age alone because age itself is not the determinant for dehydration tolerance. According to Horowitz and Hale (2001), high incidents of heat stroke amongst the elderly was NOT due to their age related diminished sensitivity or capacity to sweat, but rather due to their reduced cardiovascular performance

The conclusion is that whatever the underlying causes for inefficient thermal adjustment, older people may be in a high-risk category for dehydration. HOWEVER, they should not be excluded from working in hot environments, but special care should be taken to monitor their work loads, sweat rates (daily sweat loss and water intake etc) and their general well being. As with all workers, the exclusion of older workers cannot be based on age, but on ability to tolerate and cope with the effects of heat strain and subsequent dehydration.

7.4 Effects of Physical Fitness on Dehydration Tolerance

Aerobic capacity of a person is also related to heat tolerance. A person with efficient heat tolerance can more easily avoid dehydration than a less physically fit person. At rest (sedentary work in a hot environment), the rate of sweating and dilation of the blood vessel depends on the aerobic capacity or the physical fitness of the individual (Dukes-Dobos, 1995). The rate of sweating and extravasation of the blood vessels to dissipate heat from the body will govern whether the person can tolerate dehydration and for how long. In conclusion there is a strong correlation between physical fitness and capacity to withstand dehydration.

Windle and Davies (1996) observed that while wearing nuclear, biological and chemical (NBC) protective clothing and undergoing standardised exercise, individuals with high VO_{2max} and a low relative body mass [75ml/kg LBM/min] had lower heart rates, higher sweat rates and longer tolerance times for heat stress when compared to individuals of moderate fitness [60ml/kg LBM/min].

Cheung *et al* (2000) conducted studies with different protective ensembles to see whether endurance training had any effect on the reduction of heart rate and core temperature. Endurance training significantly increased VO_{2max} by 15 % and significantly reduced core temperature and heart rate. As a result, heat tolerance was increased in response to intense exercise at 40°C for 2 hours, when compared to the control group. Sweat rate was elevated after endurance training, however evaporative heat loss was unchanged when protective clothing (NBC) was worn due to reduced evaporation.

McLellan and colleague (1999) studied the effects of dehydration on subjects with protective clothing after exercise and on their subsequent exercise tolerance time (TT). The participants walked on a treadmill at 4.8km/hr for 100 minutes in a hot (35°C dry bulb, and globe temperature, 50% humidity) condition with a wind speed of 1.1m/s. The subjects were either euhydrated or dehydrated (2.5% of body weight). It was determined that there was a reduction in the time taken to reach the limits of heat tolerance as a result of dehydration and that this effect was accentuated due to uncompensable heat stress with NBC clothing.

7.5 Effects of Health Status on Dehydration Tolerance

In summary, mild levels of dehydration with fluid restriction during exercise significantly impairs TT in an uncompensable heat stress environment. In a similar situation people with cardiovascular problem, diabetes, obesity, skin allergies, dehydration illness and also the undernourished have reduced levels of heat tolerance. Any type of illness, sleep deprivation, recent alcohol consumption, lack of acclimatisation, lack of physical fitness and certain medication can also reduce body's mechanism for tolerance of heat (Turunen, 1999).

7.6 Effects of Gender on Dehydration Tolerance

The core temperature of eumenorrheic women changes according to their ovulatory cycle, being higher during ovulation. The endogenous estradiol and progesterone modulate body temperature. Depending on the serum level systemic progesterone increases and estradiol decreases core temperature at different stages of the ovulatory cycles (approximately 0.4°C higher during the luteal phase compared to the follicular phase (Horvath and Drinkwater, 1982)). These differences are associated with changes in thermoregulation and fluid replacement, which always lowers core temperature as observed by Cheung and McLellan (1998).

Grucza et al (1987) investigated the effects of dehydration prior to heat exposure on sweating and body temperature. Eight males and eight females were tested and dehydrated to 1,3 and 4% of their body weight. It was concluded that dehydration affects sweating and body temperature in men more severely than in women.

Women on oral contraception may have to be aware of their hydration status. Stachenfeld *et al* (1999) have studied the effect of oral contraceptive on body fluid regulation. They have studied 25 women during 150 minutes of dehydrating exercise followed by 180 minutes of self-rehydration. The women were on oral contraception for 4 weeks prior to the test. When 17-beta estradiol concentration was high, plasma osmolality was low, indicating a lowering of osmotic operating level of fluid regulation. This marker also changed at different stages of the menstrual cycle. This indicates that oral contraception may affect the osmoregulation of women on the contraceptive pill.

7.7 Effect of pregnancy on dehydration

During pregnancy the cardiovascular demand on the body increases and the internal temperature slightly rises. For these reasons heat tolerance decreases during pregnancy (Lary, 1984). The requirement for blood flow to the uterus overrides all other needs. Thus the requirements for extra blood flow to skin for cooling of the body temperature may be compromised during pregnancy. Thermal responses to heat, exercise, cold and raised core temperature are regulated by the changes of various hormones during pregnancy.

In addition, pregnant women in their first trimester almost always suffer from morning sickness. Vomiting leads to dehydration unless the liquid is replaced. Uncontrollable nausea and vomiting during pregnancy will result in dehydration. In a hot environment and/or after hard physical activity this group will be dehydrated to a greater extent than the normal population.

Heat stress and resulting dehydration can also occur from outdoor as well as indoor occupations. Fire fighters, workers from steel, ceramic, foundry, paper mils, nuclear power stations, bakeries, saunas and steam room attendants are in the risk category. Dehydration can occur without any warning.

Breast-feeding provides a powerful thirst stimulus in the lactating mother, which can result in a 12-16% increase in fluid amongst western women. In western women, moderate dehydration doesn’t affect milk production, however it is not known how lactating women in hot and/or dry climates respond especially if water supplies are limited.

8 Limits of Dehydration

Goldman (1988) provides the following descriptions of the possible consequences of not replacing lost sweat:

- ± 1 litre lost = worker feel tired
- ± 3 litres lost = worker finds it difficult to perform
- ± 4 litres lost = worker finds it difficult to continue
- It is common practice to express water loss in terms of percentage of loss of body weight. The following table is also taken from Goldman (1988).

Weight Loss (Kg)	Level of Dehydration (as % of 70kg body weight)	Degree of Distress
2	3	Some physiological upset
3.5	5	Risk of heat/dehydration exhaustion
5	7	Dangerous hallucinations
7	10	Very dangerous high risk of heat stroke; total incapacitation likely

- The above limits can be reached in 1 to 2 hours when the air temperature is greater than 27°C and workers are wearing PPE and working continuously.
- Dehydration can occur during a single work shift (even when rest periods are introduced) or over a period of several days work.
- Sweat rates can easily exceed a litre per hour under extremely hot conditions.

In terms of a maximum sweat rate limit, there are currently no maximum limits described in any of the relevant International, European or British Standards. BS EN 12515 (1997). “Hot environments – Analytical Determination and Interpretation of Thermal Stress Using the Calculation of the Required Sweat Rate” recommends maximum values for water loss from the body of 4-6% of body mass depending upon whether the subjects are acclimatised or not. These values should be seen as minimum values of sweat loss that can be exceeded by most people who are physically fit. However, in terms of total body water loss (when corrected for fluid and food intake and urine and faeces excretion) it is considered reasonable to adopt a limit value of total body water loss of 5 % of the body mass

8.1 Re-hydration Considerations

Normally in moderate heat and moderate exercise conditions, a considerable amount of water is lost through urine, sweat, respiration and to a lesser extent through faeces. To maintain the fluid balance, people normally require approximately 2.5 litres of water every day. However, in hot conditions and in situations where their metabolic activity is high, this requirement may go up to 3.5 litres (Guyton, 1981). This loss of water must be replaced either by drinking or from the water content of the diet. Individuals going through the process of dehydration should be well hydrated. Drinking water, juices, soda, sport drinks or any other liquid beverage not concentrated or containing diuretics can achieve this. Therefore in industry and all work places where dehydration is a risk, a re-hydration procedure should be implemented with provision being made for the regular supply of fluids and water before and during any work in warm and hot environments where the metabolic rate is high and where PPE is worn.

8.2 Cumulative dehydration

As dehydration has a cumulative effect over a period of time, an adequate re-hydration programme is essential. As reported previously, Kampmann *et al* (1998), demonstrated in a dehydration study using miners, that whilst dehydration may not be significant over one shift, the cumulative effect over several shift were and the miners became significantly dehydrated. The rate of dehydration was dependent on the high climatic stress and the degree of physical work the workers had to perform. This cumulative effect is further exacerbated as it may take two to three days for a person to re-hydrate completely after a fluid loss of 4% to 7.5% of body weight (Lamb, 1978). Horowitz and Hales (2001) have stated that a 3% loss of body weight results in a reduction in sweat rate and skin blood flow. This will increase core body temperature and precipitate dehydration.

8.3 Personal Protective clothing:

Workers who are required to wear protective clothing in industries such as chemical plants, asbestos removal, nuclear power plants and hazardous waste storage sites are at significant risk from overheating and dehydrating. The protective clothing used in these industries is usually impermeable to vapour, which will obstruct sweat evaporation and impair heat transfer due to high insulation. The maximum heat loss and gain is usually from the head rather than the rest of the body (although this depends on the type of PPE worn).

Cheung *et al* (2000) conducted studies on eight healthy males with different protective ensembles to see whether endurance training had any effect on reduction of heart rate and core temperature. Protective clothing (NBC) and usual combat clothing were used for the test. Acclimation was shown not to have an effect on heat strain when NBC ensembles are worn. It was also determined that sweat rate was elevated after endurance training, however the evaporative heat loss was unchanged due to reduced evaporation. In contrast, in the group with usual combat clothing, there were significant reductions in heart rate and rectal temperature after endurance training. Obviously the protective clothing such as NBC was the cause of over heating, with increased core temperature and heart rate, which in turn will lead to dehydration.

In industry were dehydration issues may be expected workers should be encouraged, where possible, to wear lightweight, loose-fitting cotton clothing, as this ensemble will allow heat to transfer from the body efficiently and not impede the evaporation of sweat nor encourage the production of it through heat stress. However if protective clothing is required a compromise must be made even if it involves regular fluid intake as a payoff for complete impermeability of the material.

8.4 Voluntary or Positive Re-hydration

The U.S. navy studied the effect of positive hydration with two groups of 80 recruits (Theodore and Shiffer, 1988). They were asked to perform the usual physical military training with or without a positive re-hydration program. In addition to having their usual fluid intake voluntarily, the re-hydrated group also received water before, mid way and after the training seasons. In a field study they observed that dehydration was a problem even at mild temperatures and reduced humidity (Wet bulb gradient temperature 18 to 20°C). Urine samples were collected after three days of exercise and the specific gravity of the urine was measured for dehydration. There were significant differences in the dehydration status of the rehydrated group and the control group.

The most worrying concern in this study was that it demonstrated again that thirst does not give a good indication of hydration status. Voluntary water intake resulting from the feeling of thirst cannot keep pace with the real status of dehydration as mentioned in the study of Sohar et al in UNESCO Indian symposium on Environmental Physiology and Psychology reviewed by Hubbard and Armstrong (1988).

8.5 Acclimatisation

Acclimatisation helps the body to adapt to heat stress and thus reduces dehydration. After acclimatisation the body can tolerate heat for longer periods and the standard of physical and cognitive performance may not deteriorate to the same degree. For the new recruit acclimatization usually starts at a lower level with a minimum of 5 days exposure with a 20% increase in exposure to heat stress. For experienced workers the recommendation is for 3 days starting at 50% heat exposure (Bernard, 1996).

Senay (1972) and Montain and Coyle (1992) observed that after acclimation, plasma volume and protein content are not affected by dehydration to the same extent as it is affected in the non-acclimatised person. Senay put forward a possible explanation for this. It was believed that with acclimatization the initial instability of thermoreceptors and baroreceptors as a result of heat exposure was corrected. This helps to maintain protein content and plasma volume under heat stress in acclimatized individuals. As a consequence of becoming acclimatized, a person is able to work in a hot environment under less physiological strain and continue to work longer than a non-acclimatised person. However additional acclimatisation if needed if the environmental heat stress increases suddenly due to natural causes or through a breakdown of an air-conditioning system for example.

It is well documented that sodium and potassium concentrations in sweat increase with sweat rate and decrease with acclimatisation (Allan and Wilson, 1971). In agreement to the above finding Stirling and Parsons (1998) have suggested that workers should take a moderate sodium diet prior to and during heat exposure to avoid electrolyte imbalance as the rate of sweating increases with acclimatisation. Salting food at meal times should provide an adequate salt intake. Low sodium diets during heat exposure may increase the risk of circulatory incompetence due to a low stimulus for water intake (Armstrong *et al*, 1987).

Buskirk et al (1958) conducted a study on three groups of five men all dehydrated overnight on two occasions to approximately 5.5% of their starting body weight. During a three week period one group was acclimatised to heat and physically conditioned, the second group was physically conditioned only and the third group remained sedentary. It was determined, that physical conditioning was associated with enhanced work performance during dehydration whereas acclimatisation to heat did not appreciably supplement this effect.

8.6 Re-hydration Procedure

Re-hydration procedures should be adhered to in order to correct fluid and electrolyte intake and balance. Bates *et al,* (1996) recommend a fluid intake volume of 500 ml/h for people working in conditions with high humidity and high temperatures where the air temperature is below 45°C. Other authors have recommended a regular intake of a small volume of water over the entire exposure period (Rodahl and Guthe, 1988; Bernard *et al*, 1994). Regular intermittent drinking restores about 75% of the water lost in acclimatised workers. Rodahl and Guthe (1988) have recommended that volumes of about 100 to 150 ml be consumed several times an hour, while Bernard *et al* (1994) have recommended the intake of about 200 ml every 15 minutes.

In the case of non-acclimatised workers, water loss may be considerable. Unacclimatised persons can also have other symptoms of dehydration. Simple re-hydration procedures with plain water may not be adequate to counteract the complication of dehydration in an un-acclimatised person.

a) Commercially available Electrolyte drinks:

Although there are a numbers of commercially available fluids and electrolyte replenishment drinks for re-hydration procedures, these preparations should be considered carefully. Mudambo et al. (1997) completed a study to investigate whether ingesting water or dextrose (7.5 g .100 ml^{-1}) with electrolytes, or fructose/corn solids (7.5 g.100ml^{-1}) (400 ml every 20 min) would reduce perceived exertion associated with 16 km (3 h) walking/running in the heat compared with that perceived during exercise with no fluid intake. It was found that fatigue was caused by several interacting factors: a fall in blood glucose and plasma volume, dehydration and neuroglycopenia. Taking other fluids during exercise reduced the strain and the rating of perceived exertion; but that this was better achieved by ingesting a dextrose/electrolyte solution. However, electrolyte drinks will have variable compositions of electrolytes and carbohydrates. The consumption of these fluids may result in an overload of sodium. Furthermore, active electrolyte replacement is not always necessary because sodium loss by sweat varies from individual to individual as well as between different climatic conditions. Equally the required concentration of electrolytes and sugar in the drink depends upon the individual and their dehydration status as it is not possible to predict a person’s degree of susceptibility to dehydration from sex, age, ethnic origin and body fat content. This is only possible on an individual basis after proper physiological measurements have been taken and relevant calculations made.

b) Drinks with high Carbohydrate content:

Sugar concentrations in carbohydrate drinks may fulfil the energy requirement of the body during hard physical work. A study by Clapp *et al*, (1999) observed that total weight loss was significantly lower in a group of subjects rehydrated with carbohydrate-electrolyte rich drink than in the group rehydrated with plain water. However, the interesting finding was that the carbohydrate-electrolyte group had higher sweat rates and consumed more liquid to quench their thirst. Fluids with high carbohydrate concentrations resulted in an increased demand for more fluid into the gut to aid carbohydrate absorption. Thus, instead of alleviating the condition these carbohydrate rich drinks resulted in increased dehydration as the body diverted its water into the intestine.

Dearborn *et al,* (1999) observed that elevated plasma glucose levels may help to reduce the normal pattern of a rise in deep body temperature during exercise or hard physical work. Their study investigated healthy volunteers with or without elevated glucose levels prior to exercise (with or without standard carbohydrate breakfast). Rectal temperature, heart rate, mean skin temperature and sweat rate were monitored during the exercise period. In all parameters studied, the values were significantly lower in the higher glucose plasma level group compared to the control group (only exception was heart rate which stayed the same). The conclusion was that the high level of glucose enhanced blood flow to the periphery and extravasation increased heat loss from the body.

Contrary to the above findings, Szlyk *et al* (1991) observed that to counterbalance dehydration under mild and severe heat stress, carbohydrate-electrolyte rich fluid intake was not necessary as long as the workers were taking regular meals in between work and rest schedules. The ordinary fluid and salt content of a diet was sufficient for re-hydration.

c) Plain water:
It should also be noted that the consumption of large volumes of plain water for prolonged periods in both mild heat and hot conditions might lead to hyponatremia (low concentration of sodium in the blood) (Bates *et al* 1996, Barr and Costill1989). In addition, the excess water may simply be eliminated by urine and not used to re-hydrate the body. Therefore frequent re-hydration with smaller volumes (as recommended by Rodahl and Guthe and Bernard *et al*, 1996) is better than one large quantity of intake of liquid.

Several reports have described hyponatremia by athletes during long races due to excessive water intake to avoid dehydration. A report of the death of an Army basic trainee resulting from hyponatremia was described by Garigan and Ristedt, (1999). Continued effort of re-hydration with plain water led to pulmonary and cerebral oedema in this case.

The majority of fluid and electrolyte loss investigations in the heat have been conducted using young healthy well-trained males. These studies are unlikely to be representative of a general workforce where workers will have variable VO_{2max}, are of differing ages and possess varying functionality of their renal or cardiovascular system for example (Allan and Wilson 1971, Costill et al. 1975, Barr et al. 1991, Clark et al. 1992, Fellmann 1992)

9 Conclusions

One can conclude from the scientific findings that water taken frequently and in moderation is safe for re-hydration. The depletion of carbohydrate and electrolytes can be replenished by way of a normal diet and though drinking beverages. One study (Ray *et al*, 1998) provides evidence that the inclusion of sodium in re-hydration beverages and liquid meals increases fluid retention and improved plasma volume restoration. However the guidelines for re-hydration due to heat injury is different for civilian population and the military. A review by Cooper (1998) has concluded that dehydration in a military situation is mainly due to high physical activity for long periods of time and the endurance limitation depends on the WBGT of the environments. In civilian population and in the general workforce there are many factors that govern the risk for heat stress. Apart from environmental conditions, the health of the population, type of work and gender are some of the heat injury risk factors. Dehydration can precipitate heat injury in this group. Factors that increase the risk include old age, obesity, previous heat stroke, certain skin disorders, and people taking certain medications. Environmental conditions can also aggravates the situation. Civilian guidelines should therefore be based on the heat index and above-mentioned factors. The method of prophylactic water consumption (replacing beyond the loss of water from sweat), common for military and athletes, is not necessary in this group.

It is important to realise, that thirst is NOT a good indicator of dehydration. It is thought that the loss of electrolytes, through sweat for example, may suppress the thirst drive. This may lead to insufficient drinking in order to replenish water deficit. This may result in what is called “voluntary dehydration”. Voluntary dehydration is dependent on personal behaviour or preference for water to be at the right temperature, palatability, and availability.

It is agreed that means for voluntary re-hydration should be readily available and encouraged in workers exposed to heat.

10 Recommendations

From the literature review and from examples from different industries a safe guideline and work regime can be established for the safety aspect of the workers in heat related industries

- A constant supply of cool water ideally at about 15°C should be available to heat exposed workers and there is provision of individual drinking cups/bottles. Workers should be educated about the need to drink water in small volumes frequently e.g. 100-200 ml every 15 minutes of a working day as **thirst is NOT a sufficient incentive to drink** because heat exposure leads to a diminished thirst drive.
- To reduce the risk of dehydration, the amount of fluid consumed should be about equal to the amount of sweat lost. This can be determined practically by weighing the workers before they are wearing their PPE and after they have removed their PPE. The weight difference will indicate how much water has been lost and given an approximation of how much water needs to be consumed to achieve adequate hydration
- If the work is being conducted in an area where the provision of water is not possible, then approximately 500 ml of water per hour of work should be consumed before the work commences. This may go some way to helping them meet their fluid demands during the work period. However, if water loss is significantly greater then water intake should increase proportionately.
- The consumption of caffeinated drinks such as tea, coffee or coke during rest periods should be minimised.
- Although not stipulated in guidance, urine colour can be used as an informal indicator of hydration status. The darker the urine the greater the dehydration and therefore the greater the need to re-hydrate. This is not a reliable indicator, as urine may be discoloured by certain foods, e.g. beetroot.
- It is important to note that even if workers replenish the lost sweat with roughly equal amounts of water, they may still be susceptible to dehydration due to electrolyte imbalances brought about by excessive sweating. Wearing some types of PPE may increase sweating and cause humidity to build up in the microclimate between the skin and the garment in temperatures above 15°C. As a result, evaporation decreases and the body attempts to lose more heat by sweating more. This in turn increases humidity further.
- A well balanced diet is fundamental to ensure that workers maintain the good health they require to work in the heat. If catering facilities are provided the employer can to some extent, have direct control over certain aspects of the dietary habits of the workforce.
- Additionally employees should be encouraged to salt their food at meal times, as this is the best way to replenish the salt lost during sweating.
- The amount of salt in a normal diet is usually sufficient to meet the salt demands placed on the body due to excessive sweating. However it may be necessary to increase salt intake if workers are not acclimatised or if they have shown symptoms of the heat stress illnesses described previously.
- **Salt Tablets should NOT be taken.**
- If a worker has had their salt intake restricted due to a physicians order, the physician should be consulted.

- Recent research on dehydration has recommended a well-balanced carbohydrate and electrolyte-rich drink during the course of shift work (rather than plain water only) as this may help to reduce the degree of dehydration.

In conclusion it is clear that prior to employment workers should be medically assessed to identify any medical condition that may preclude them from working in heat stress situations. Once employed companies should regularly review using a medical health assessment an employee’s suitability of remaining working in potential heat stress environments. Also employers should be made aware that by using good work scheduling practises i.e. variation of work, limited exposure to heat stress and a regular re-hydration program risks of developing dehydration in acclimatised and unacclimatised individuals are minimised even when working in industries with hot conditions.

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