HEAT STRESS IN AVIATION

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INTRODUCTION
It is generally agreed that man’s adaptations to the heat are well developed, conversely when naked in the cold his physiological adjustment very poor. It could also be argued that humans are historically tropical as:

They rely on physiological adjustment in the heat but behavioral adjustments in the cold. The thermo-neutral ambient temperature for nude humans and the temperature necessary for undisturbed sleep is high at 27°C and humans have substantial physiological adjustments to the heat but modest cold acclimatisation.

BACKGROUND
Temperature regulation is a classic example of a biological control system. The balance between heat production and heat loss is continuously being disturbed, either by changes in metabolic rate (exercise or work being the most powerful influence) or by changes in the external environment, which alters heat loss. These resulting changes in body temperature can adversely effect the function of body systems and organs. As a result, heat production or heat loss processes are triggered in order to restore normal body temperature. If the heat generating systems of the body are excessive, as is the environment, then the capacity of the body to maintain thermal homeostasis is exceeded and can lead to a serious threat to health, or even death. In addition this health deficit severely effect an individuals capacity to work optimally, the end result is poor health and cognition. Strategies to minimise or eliminate this effort will benefit the performance of persons working in the aviation industry.

Normal body temperature
The temperature of the deep tissues of the body - the core - remains almost constant, within ± 0.5°C, day in and day out. The range of normal body temperature is between 36.0°C and 37.5°C. Even when exposed to temperatures as low as 10°C and as high as 40°C in dry air, the body can maintain an almost constant internal body temperature. The surface temperature, in contrast to the core temperature rises and falls with the temperature of the surroundings. It is the surface temperature of the body that is important when the ability of the body to lose or gain heat to the surroundings is considered.

Heat balance equation
Body heat is gained directly from the reactions of energy metabolism (physical work). When muscles become active their heat contribution can be tremendous. For example, at rest the rate of body heat production is relatively low; the resting oxygen consumption is approximately 250mL/min corresponding to a rate of heat production of 70watts. During work, the rate of oxygen consumption can increase eightfold, and the rate of heat production is correspondingly increased. Heat is lost by the physical mechanisms of radiation, conduction and convection, and the evaporation of water from the skin and respiratory passages.

There are six factors that influence a person’s state of heat balance

1) Air temperature (dry bulb temperature) Above 35°C it can increase heat gain by convection
2) Humidity (relative humidity, wet bulb temperature) The importance of humidity in human heat exchange lies in it’s effect on evaporation of sweat.
3) Radiant heat (globe temperature) its direction depends on the absolute temperature difference between the body and surrounding surfaces. It is not effected by air temperature or humidity. This can be considerable in military and small aircraft which have canopies or no air conditioning
4) Air movement Depending on the air temperature, this can have a marked effect on heat exchange by convection.
5) Clothing This can also have a major effect on the amount of heat lost or gained by the body. Flight ensembles worn by military pilots can be a substantial addition to heat conservation.
6) Muscular activity This is particularly important as explained above as >90% of metabolic energy is given off as heat.

As ambient temperature increases, the effectiveness of heat loss by radiation, conduction and convection decreases. When ambient temperature exceeds body temperature, heat is actually gained by these mechanisms of thermal transfer. In such environments (or when conduction, convection and radiation are unable to dissipate large metabolic heat loads) the only means for heat dissipation is by sweat evaporation. The rate of sweating increases directly with the ambient temperature.

The total amount of sweat evaporated from the skin depends on three factors: the surface area of skin exposed to the environment, the temperature and humidity of the ambient air and, the convective air currents around the body.
By far, relative humidity or wet bulb temperature is the most important factor determining the effectiveness of evaporative heat loss. When humidity is high the ambient vapor pressure approaches that of moist skin and evaporation is greatly reduced. Thus, this avenue for heat loss is essentially closed, even though large quantities of sweat are produced. This form of sweating represents a useless water loss that can lead to dehydration and overheating. As long as the humidity is low, relatively high environmental temperatures can be tolerated.

In other words as the atmospheric air becomes more saturated with water (high RH) it is less willing to take up more moisture, including from the wet skin, thus the sweat drips off and does not loose heat from the body, sweat must evaporate to be effective in cooling the body.

ACCLIMATISATION TO HEAT
With flight crews constantly traversing continents the environmental conditions they are exposed to are constantly changing. They can be going from winter to summer and back within a week or two. This is insufficient time for the physiologial adaptation of acclimatisation to occur. In addition military aircrews can be deployed from winter environments to become operational in hot summer conditions (Gulf war). A lay over of 1-3 days in very hot conditions without acclimatisation may cause acute health deficits that may impede performance.

When people work in a hot environment for the first time, their work performance is reduced, their heart rate and core temperature increases greatly, and they are more prone to heat disorders, such as heat syncope and heat exhaustion and the far more serious condition of heat stroke. During unacclimatised work in the heat, a reduction in stroke volume is the important mechanism limiting physical performance Unacclimatised persons cannot reach a circulatory and thermal steady state during heavy work in the heat with hyperthermia and heat illness the likely end result.

Acclimatisation advantages the person by:
- increasing the plasma volume by up to 25%
- reducing the sodium lost in sweat by up to 50%
- increasing the sweat rate
- initiating sweating onset earlier

Redistributing blood to the periphery more efficiently.

The duration of time it takes to bring about these adaptive changes varies depending on whether the person is active in the heat and the duration of heat exposure. It is generally thought that 4-5 days is sufficient to acquire a good percentage of the advantageous adaptation however to fully acclimatise takes up to 14 days exposure at least. A common mistake often made is for people to stay in air conditioned rooms and so have minimal heat exposure, in fact what is gained by the exposure can be lost during the night when resting in AC. It may sound common sense but one international sports team went to a competition 2 weeks before the events to acclimatis. They stayed in an air conditioned hotel and hardly spent any time exposed to the heat. Needless to say many suffered heat illness when competition began.

FLUID REPLACEMENT FROM SWEATING
The maintenance of high sweat rates leads to progressive dehydration which is accompanied by impairment of mental and physical performance, and of heat dissipation. The intake of fluid during the work and leisure periods to replace sweat losses is imperative.

So what is the expected sweat loss of persons in hot conditions and what is the best beverage to replenish sweat loss. There is an upper limit to the rate of gastric emptying and intestinal absorption (1.5 litres per hr). Drinks with high concentrations of carbohydrate (sugar) and electrolytes (salts) have relatively slow rates of gastric emptying, and are thought to impede fluid replenishment. In some situations there may be a need to replace the electrolytes lost in sweat, although most people now agree that in normal circumstances electrolyte replacement is not indicated (if people are eating a normal diet).

Some commercially prepared drinks have varying concentrations of glucose and sodium, ranging from isotonic (140 mmol/L) to hypotonic (25 mmol/L) to plasma. Sodium is added to the drinks for the purpose of replacing sweat salt losses, and to aid in the transport of glucose across the intestinal wall. Glucose is added to the drinks in order to maintain blood glucose levels (energy). Sweat is hypotonic to plasma and to many of the electrolyte replacement drinks available. Consequently, the consumption of these electrolyte replacement drinks, if consumed as a sole replacement beverage may result in excess sodium. On the other hand, if sweat losses were replaced with plain water a dilution of the plasma may occur and inadequate plasma sodium could result. It should be emphasized that sweat losses can exceed 2 litres/hour when in very hot conditions (pilots in full combat flight suits). Meals taken at regular intervals in order to allow salt and glucose intake is a must. Another problem with commercially prepared electrolyte and energy replacement drinks is the ph. They are usually between 2-3 which is very acidic. Frequent consumption of large volumes of such drinks may have long term renal effects due to the hydrogen ion load.

The cabin environment of commercial aircraft is warm and very dry (RH 20-30%). This results in significant insensible fluid loss from respiration. Fluid loss of a sedentary person such as a pilot would be between 200-300ml per hour. The loss from flight attendants would possibly be 300mls depending on their activity level. Military pilots in full flight suits would conceivably be as high as 600ml per hr.
Sweating results in sodium and potassium loss. Generally speaking this avenue for electrolyte loss would be minimal for pilots whilst flying, however when off duty in hot environments it is important to increase fluid intake in order to start work in a euhydrated condition (see power and work capacity decrements with hypohydration). The loss of sodium in sweat is around 30-50 Mmol/L and potassium 3-6 Mmol/L. Given these average losses it is not necessary to consume special fluids as long as regular food intake is maintained, this would be sufficient to replace all lost electrolytes. Water is still the best replacement fluid despite the very successful commercial push to alter this thinking.

OTHER FACTORS THAT INFLUENCE HEAT LOSS AND THERMOREGULATION
There is a significant variation between an individuals ability to thermoregulate, VO2 max (fitness), differing ages, body composition and ethnicity being the principal ones.

It has been shown that increased BMI is a risk factor for heat illness. In addition a low VO2 max has also been shown as a pre-disposing risk factor.
Females generally have a higher percentage body fat and it has been suggested that endocrine hormones may interfere with thermoregulatory processes, however, these potential adverse effects would be minimal. Generally speaking as we get older physiological mechanisms deteriorate, GFR decreases so electrolyte balance could be delayed, likewise the affect of ADH on the renal collecting duct may be impaired. We could therefore expect as we get older our ability to maintain core temperature in hostile conditions would decline. This age decline effect would not be linear, the greatest decline would be in the latter years.

POWER AND WORK CAPACITY DECREMENTS WITH HYPOHYDRATION AND DEHYDRATION
The hypohydrated state has been shown to impair both mental and physical performance. Body water deficits from sweating of a mere 1-2% of body weight results in a 6-7% reduction in physical work capacity in a moderate environment. Water deficits of 3-4% in the same environment results in a 4-8% reduction in maximal aerobic power, and a 22% reduction in physical work capacity. Body water losses of 4% in a hot environment results in a 25% reduction in maximal aerobic power with a physical work capacity reduction of approximately 50%. Cognitive performance is also affected adversely by hypohydration. Mental performance begins to show a decrement at 2% hypohydration, with further mental impairment being proportional to the degree of hypohydration. All measured mental functions, including short term memory, arithmetic accuracy and attention were all significantly impaired at 2% hypohydration in one study. It was also postulated that the decrements in mental performance were mainly due to dehydration, rather than the direct effect of elevated core body temperature on brain function. In addition the level of mental attention determines work performance, and that complex tasks may not be adequately or safely accomplished when attention is impaired by environmental stress.

THE HEALTH EFFECTS OF HYPERTHERMIA
Heat illness comprises the following three main conditions:
1) Heat cramps
2) Heat exhaustion
3) Heat stroke
The term heat cramp is misleading. The heat does not elicit cramps in the muscle, it is more likely to be due to an acid-base imbalance in the body (hyperventilation causing alkalosis). It is now generally believed that muscle cramping is far more complicated than mere salt depletion, it may well be due to regional microcirculatory changes. Heat exhaustion is the inability of the circulation to meet metabolic and thermoregulatory demands. Generally speaking those persons are unacclimatised, unfit, obese or dehydrated and therefore more prone to this condition. Weakness, inability to continue working, frontal headache, anorexia, nausea, faintness, and in some cases syncope are the usual signs. The body temperature is normal or slightly elevated, sweating is normal but the skin can be pale. The heart rate is often very high, and the blood pressure low. The common end point of this condition is for the person to report sick or alternatively faint should they ignore the body’s warning. Often drinking water and rest in a cool place will be sufficient to revive the individual however, in some cases intravenous infusion of fluid may be needed.
Prickly heat is a term used to describe skin inflammation in the heat, especially following profuse sweating. The sweat gland ducts become blocked and so the sweat is forced out across the wall of the sweat duct into the tissue under the skin. Infection of the skin can result. Thermoregulation is compromised in this state, removal from the hot environment and good hygiene is often sufficient to eliminate or prevent it.
Heat stroke is a possibility in persons who are highly motivated or for those in paced labor in the heat. The mortality rate is around 80% for people who develop this condition. The body gets to a temperature that causes tissue damage; brain, liver and kidneys being the principal organs effected.
Heart rate and core temperature elevation are the usual physiological signals indicating heat stroke.
In addition to the well known effects as stated above a recent paper has documented the haematological and biochemical changes that occurs with heat exhaustion.
A summary of the findings in this study are:
White cell count increases significantly. This is due to a rise in neutrophils, a typical stress response. Monocyte concentration is elevated which may be due to cytokine production and eosinophils significantly decrease (eosinopenia)
There was however no alteration to the plasma concentration of both sodium and potassium suggesting that hyponatremia is not the cause of cramps (most suffered cramps). The chloride and bicarbonate conc decreased with an elevated anion gap.
This shows a clinical picture of metabolic acidosis. Other findings were:
Elevated glucose conc
Raised urea and creatinine conc
Serum osmolality significantly raised. Creatine kinase, aspartate transaminase and lactate dehydrogenase were raised.
Alanine transaminase was also raised in many patients.
Serum ferritin elevated
Serum urea and creatinine conc correlated well with persons who experienced cramps but not sodium.

In summary heat exhaustion has several haematological and biochemical markers. Neutrophil leukocytosis, eosinopenia, metabolic acidosis, increased glucose and ferritin, and a mild rise in creatine kinase, AST and lactate dehydrogenase.

Long term health effects of heat exposure/dehydration
Renal calculi is a well known long term consequence of inadequate fluid intake. A recent report states that 1 million Australians suffer from renal stones. I have been informed by the attending physician that renal calculi was the most common health problem amongst Saudi pilots. They consumed mainly coffee and caffinated drinks, and even people in their second and third decade had stones.

In a recent study reported in the New England Journal of Medicine, a clear relationship was shown between poor fluid intake and Ca of the bladder.

**IN SUMMARY**
The key to maintaining good health is to avoid hypohydration. Train to drink by schedule. Do not depend on thirst.
When in hot regions drink more fluids. There is no way to train to reduce water requirements, it is not an adaptive response.
On average you will be loosing around 200-300mls/hr when flying
Consume food on a regular basis, this is sufficient to replace all lost ions and nutrients.

Pearls of wisdom