Heat: Performance Impairment and Mitigation

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Outline

- Background.
- Impact of heat: heat illness
- Impact of heat: performance
- Wind technicians
- Strategies to help alleviate the effects of heat
  - Climate assessment
  - Screening
  - First Aid/Physiological interventions
  - Technical interventions

Occupational heat stress

(Dreosti, 1950 Adolph, 1964)

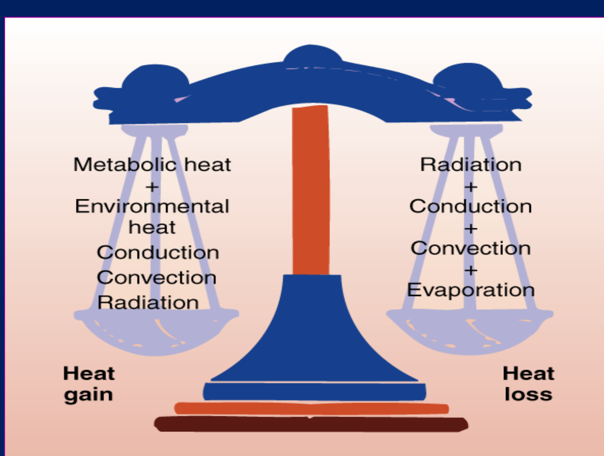
Customised interventions

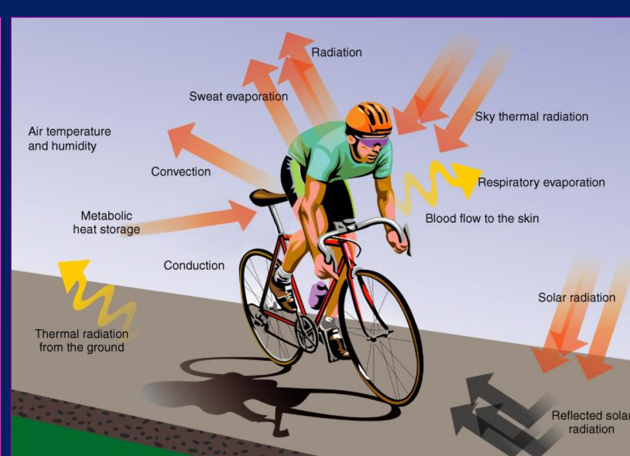
Heat tolerance screening tests (Dreosti, 1950)

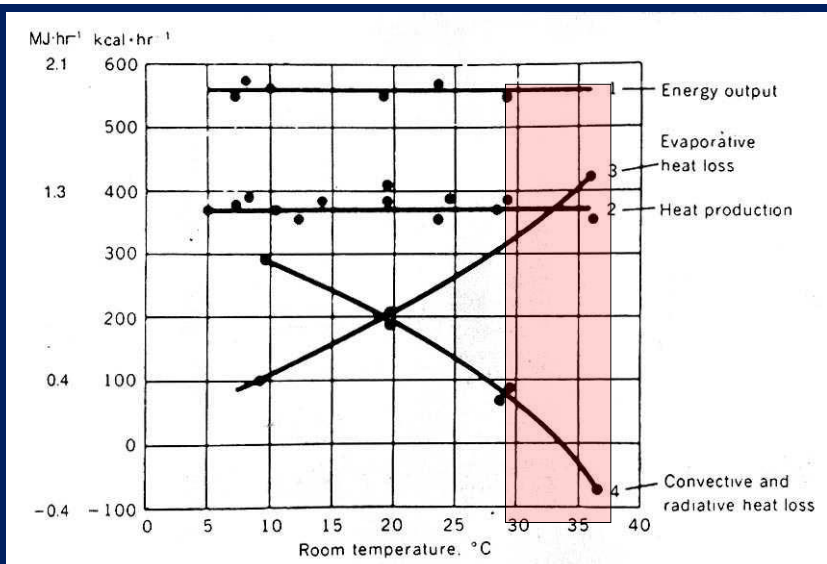
- 42,148 gold mine workers tested
- 25% naturally heat tolerant
- 15% naturally heat intolerant
- Screen employees, customised acclimation?


ROYAL NAVY

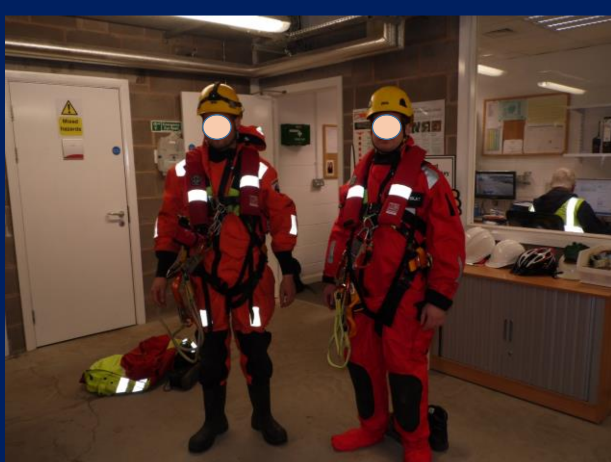
Thermal balance & heat exchange with the environment







Heat exchange during exercise (150 Watts) at different room temperatures in a nude subject. Modified from M Nielsen (1938)



If the body were prevented from losing any of the heat it produced, a fatal level of heat storage would be reached in about:

- 4 hours when at rest
- 25 minutes with moderate exercise

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Impact of skin and deep body temperatures

Skin temp (°C)	Consequence
42+	Burns
33-41	Hot
28-33	Comfort
25-28	Cool discomfort
20	Impaired dexterity
15	Pain
10	Numb
5	NFCI (with time)
<-0.55	Frostbite

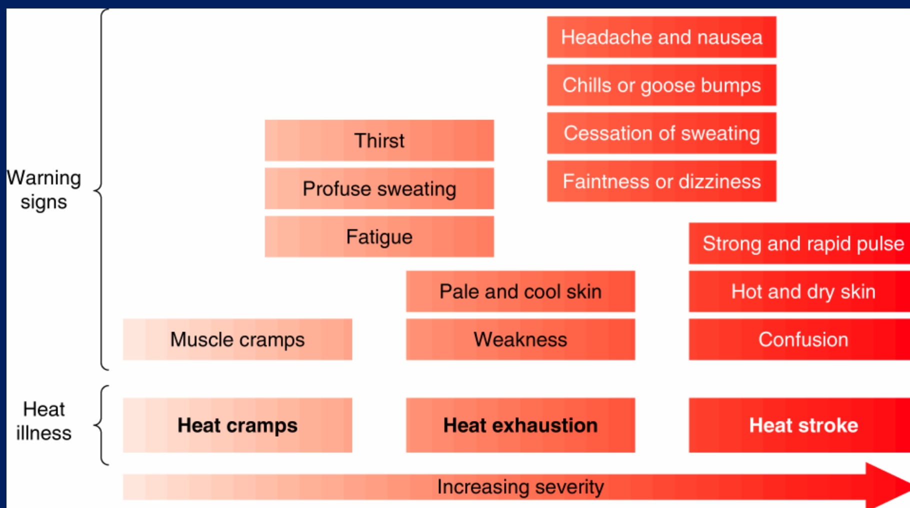
Core temp (°C)	Consequence
42-44	Death
40-44	Heat Stroke
37.5-40	Hyperthermia, heat syncope, heat exhaustion
36.5-37.5	Normothermia
36-33	Mild hypothermia
33-25	Moderate hypothermia
<25	Profound hypothermia and death

Taylor, Mekjavic & Tipton (2008)

Disorders in which heat is an aetiologic factor

- Sunburn
- Heat related skin disorders
- Heat cramps
- Heat syncope
- Heat exhaustion
- Heat stroke:
  - Classic
  - Exertional

Warning signs of heat disorders



Work Performance Impairment with Heat Stress

Three primary mechanisms:

1. Effects on cardiovascular function: with increasing deep body & skin temperatures, increase in SBF & cutaneous venous volume compromises cardiac filling and SV. HR increases to preserve Q (e.g. Cheuvront et al, 2010)
2. Effects on muscle function: muscle hyperthermia leads to fatigue due to increased rates of muscle glycogen utilisation leading to substrate depletion + decreased oxidation rates of ingested CHO (e.g Febbraio, 2000)
3. Effects on the central nervous system (CNS): above a 'critical' core temperature of ~40^{O}C, there is reduced 'central command' to exercise - fatigue & increased RPE) (e.g. Nybo & Nielsen, 2001)

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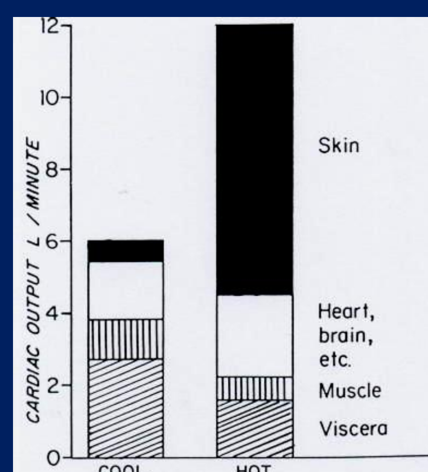
Cutaneous vasodilatation: the initial response to heat stress

- Small central heat loads lead to hyperaemia in the feet, hands and facial extremities, whilst greater heat loads (core temperature > ~37.5^{O}C) recruit the skin of the limbs and trunk
- Maximum vasodilatation can lead to cutaneous blood flows of > 5 L.min^{-1} in a 70kg man (representing a 15 – 20 fold increase from the thermoneutral state)
- A consequent fall in mean arterial blood pressure can occur by the time deep body temperature has risen by 0.5 °C (Fan et al.2008)

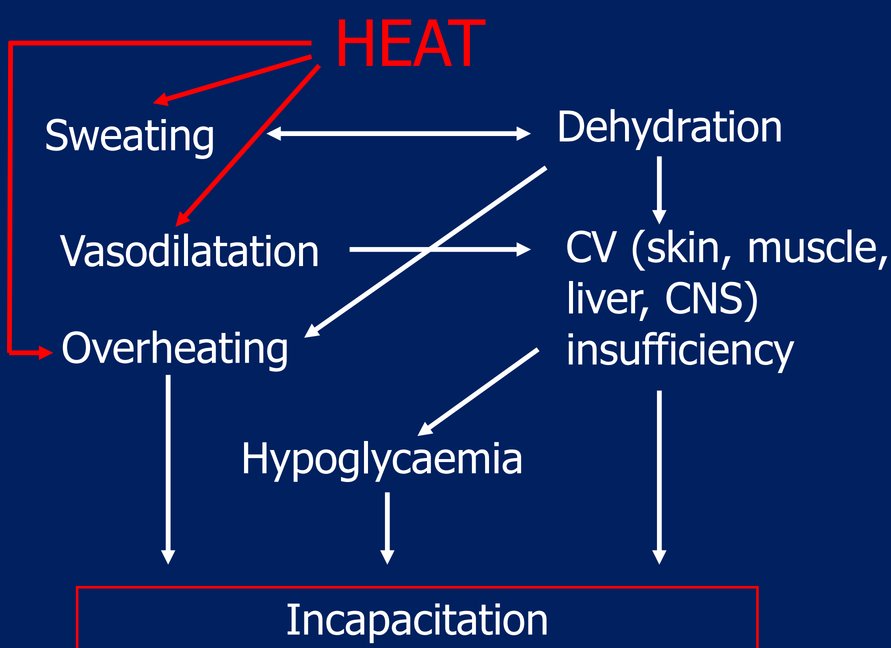


Dehydration

- Fluid loss equivalent to 1 % to 5 % of body mass increases deep body temperature due to decreased sweating and cutaneous blood flow
- Dehydration between 1.9 % and 4.3 % of body mass can reduce physical endurance time by 22 % to 48 %
- The risks of light-headedness, fatigue and heat illness are increased if exercising or resting in the heat in a dehydrated state.
- Dehydration and decreased blood pressure reduce skin blood flow which can impair skin circulation and sweating, resulting in higher skin temperatures
- Hydration status can be monitored using a variety of techniques e.g. urine charts
- In the work-place the most straightforward approaches for ensuring people maintain hydration levels are to have fluid freely available, encourage people to drink a little more than they need to quench their thirst

Mild Heat Illness

- Heat-related light-headedness/syncope (fainting)/hypotension (low blood pressure)
  - Dehydration and vasodilatation can put a significant strain on the cardiovascular system. A mismatch between peripheral vasodilatation and increased cardiac output can compromise mean arterial blood pressure
  - Most likely form of heat illness for those experiencing passive heating, such as might occur at rest in warm environments in the cabin of a transfer boat. It increases the likelihood of people feeling light-headed on assuming an upright posture
  - The longer an individual remains in the heat, the more dehydrated they become, the more clothing (including protective clothing) they are wearing - the more likely they are to experience this form of heat illness.



In the interplay between BP regulation and temperature regulation, BP usually take precedence

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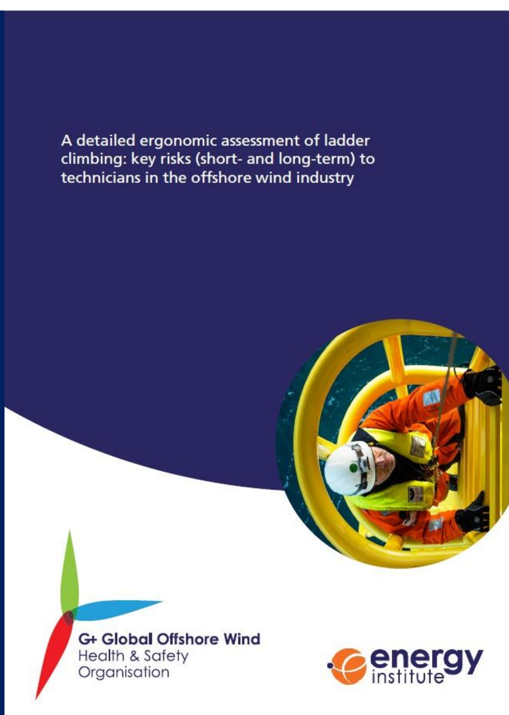
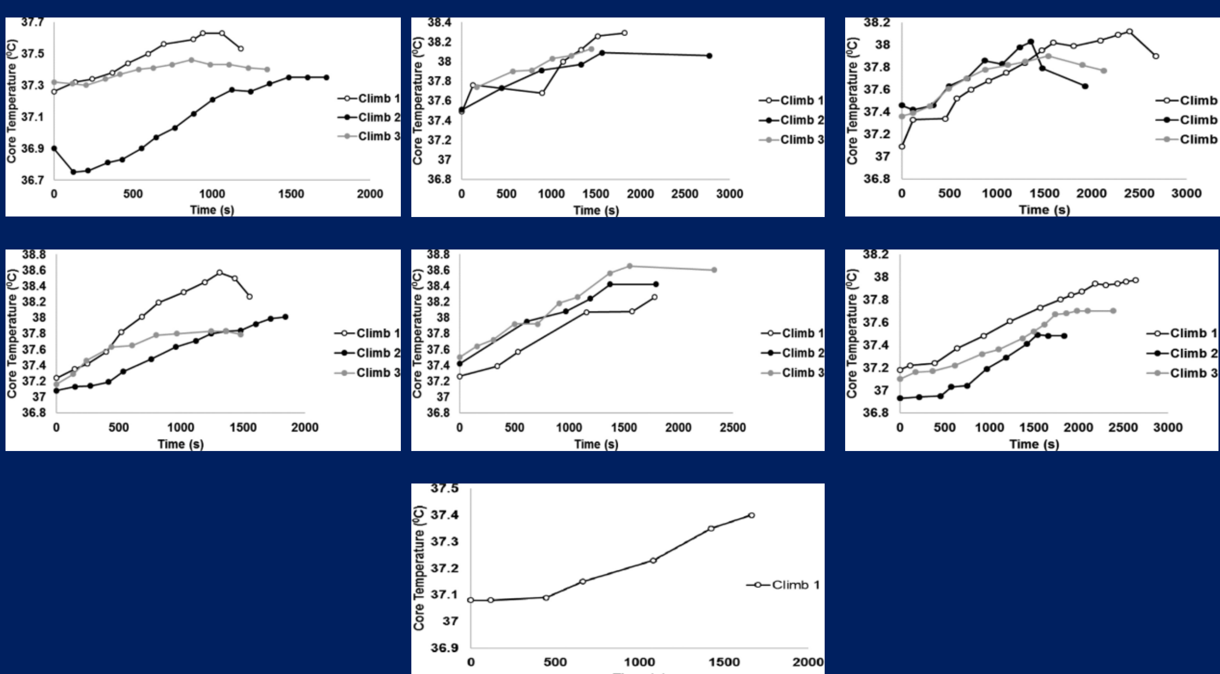


- Temperature data: 7 experienced WT, during 3 x 120 m climb (SS climb 1, Overalls 2 & 3). Each climb: 30 m climb then rest 1:1 ratio x 4 (total mean time 23 min in a SS, 20 min in overalls).
- Ta 20 °C, 52 % rh, still air, no radiant heat load
- Mechanical efficiency and total heat production were calculated for climbing in a sea survival suit and overalls

Thermal assessments of wind technicians

- The mean (standard deviation) mechanical efficiency during the climbs:
  - Survival suit: 14.6 (3.4) % (i.e. 85.4 % of the energy consumed released as heat).
  - Overalls was 16,3 (5,12) % (walking is 35 % to 40 % efficient)

- The best ladder climber achieved a ME that was approximately 5 % higher than the other participants - this was also reflected in a relatively slow rate of rise of deep body temperature in this individual (less heat produced for work done)



Wind technicians ladder climbing: estimated time to reach a deep body temperature of 38.5 °C when climbing and resting volitionally

(Calculated on the basis of direct measurements in the present study, as well as calculated theoretical maximum changes (worst case, no heat loss) from heat production data)

- Mean (SD) change in deep body temperature (Tpill) in the survival suit was: 0.76 (0.26) °C (n = 6) mean rate of increase in Tpill was 0.033 $°C.min^{-1}$.
- Mean (SD) change in Tpill in the overalls was: 0.485 (0.22) °C (n = 10) mean rate of increase in Tpill was 0.024 $°C.min^{-1}$.

Condition	Time to 38,5 °C (min)
Survival Suit using Tpill data from current study	45,5
Overalls using Tpill data from current study	62,5
Survival Suit using calculated worst case scenario (no heat loss)	14,3
Overalls using calculated worst case scenario (no heat loss)	14,2

Conclusions

- WT are likely to settle upon a work/rest schedule that means they can climb 120 m without a direct risk from hyperthermia; dangerous levels of hyperthermia are unlikely to occur with less than 10–20 minutes of continuous moderate exercise. This may change if several climbs are undertaken in a day and the later climbs are commenced with a raised deep body temperature
- More concerning is the indirect risk: that is, impact of heating on discomfort, cardiovascular control and the maintenance of blood pressure. This may lead individuals, particularly if dehydrated, to feel light-headed, excessively fatigued (observed in one participant)
- From the thermal perspective, those with responsibility for the well-being of WT should ensure that the technicians have the opportunity to cool down and rehydrate following prolonged ladder climbs e.g. 30 m to 120 m
- High aerobic fitness and technical ladder climbing skills should be encouraged/ taught – these have a directly beneficial impact on the stress and heat production associated with ladder climbing

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Environmental Assessment

To measure the environment we need to measure at least three variables:

Air Temperature
dry bulb thermometer (T_{db})

Radiant heat
globe bulb thermometer (T_g)

Humidity
wet bulb thermometer (T_{wb})

$$WBGT = (0.1T_{db}) + (0.2T_g) + (0.7T_{wb})$$

ACSM WBGT Guidelines for Races 2014

WBGT >28° C Black Flag: Cancel or recommend voluntary withdrawal. (Races that are always held in these conditions should acknowledge the extreme heat risk to the poorly acclimated and non-resident competitors in the pre-race literature and the pre-race announcements)

WBGT 23° C - 28° C Red Flag: Recommend participants at increased risk for heat collapse withdraw from race and others slow pace to match conditions.

WBGT 18° C - 22° C Yellow Flag: Recommend participants at increased risk for heat collapse slow pace. Warn entrants of increased risk of heat collapse.

WBGT <18° C Green Flag: Collapse can still occur. Decreased risk of hyperthermic and hypothermic collapse.

WBGT <10° C White Flag: Increased risk of hypothermic collapse.

The Heat-stress index

	Air Temperature (°C)										
RH %	**21.1**	**23.9**	**26.7**	**29.4**	**32.2**	**35**	**37.8**	**40.6**	**43.3**	**46.1**	**48.9**
0	17.7	20.6	22.8	25.6	28.3	30.6	32.8	35	37.2	39.4	41.7
10	18.3	21.1	23.9	26.7	29.4	32.2	35	37.8	40.6	43.9	46.7
20	18.9	22.2	25	27.8	30.6	33.9	37.2	40.6	44.4	48.9	54.4
30	19.4	22.8	25.6	28.9	32.2	35.6	40	45	50.6	57.2	64.4
40	20	23.3	26.1	30	33.9	38.3	43.3	50.6	58.3	66.1	
50	20.6	23.9	27.2	31.1	35.6	41.7	48.9	57.2	65.6		
60	21.1	24.4	27.8	32.2	37.8	45.6	55.6	65			
70	21.1	25	29.4	33.9	41.1	51.1	62.2				
80	21.7	25.6	30	36.1	45	57.8					
90	21.7	26.1	31.1	38.9	50						
100	22.2	26.7	32.8	42.2							

Heat cramps

Heat Exhaustion

Heat Stroke

SCREENING FOR SUSCEPTIBILITY TO HEAT

J Sport Rehabil. 2007 Aug;16(3):215-21.

The heat tolerance test: an efficient screening tool for evaluating susceptibility to heat.

Moran DS[1], Erlich T, Epstein Y.

⊕ Author information

Abstract

CONTEXT: Individuals in the population who are not able to sustain heat and whose body temperature will start rising earlier and at a higher rate than that of others, under the same conditions, are defined as "heat intolerant."

OBJECTIVES: The applicability of the heat tolerance test (HTT) in identifying individuals' tolerance/intolerance to heat is presented.

SETTING: HTT is performed according to the following protocol: 120 minutes exposure to 40 degrees C and 40% relative humidity in a climatic chamber while walking on a treadmill, dressed in shorts and T-shirt, at a pace of 5 km/h and 2% elevation. Rectal temperature and heart rate are continuously monitored, and sweat rate is calculated.

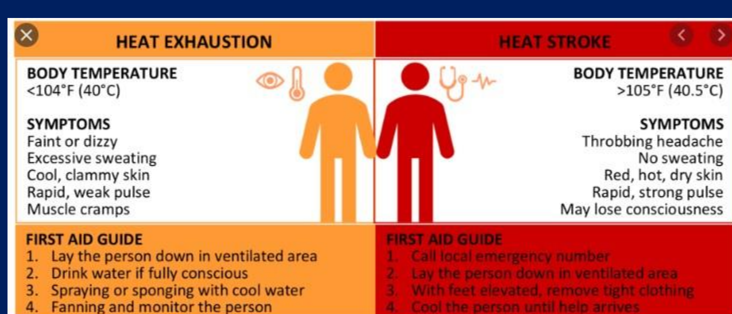
RESULTS AND CONCLUSION: The HTT that is based on controlled exposure to an exercise-heat stress is an applicable and an efficient tool in differentiating between a temporary and permanent state of heat susceptibility.

Heat screening test

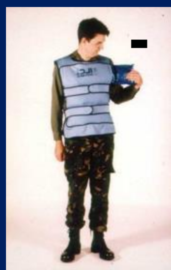
- Standardised & Specific
- Reproducible
- Titrate and thereby identify upper limit of thermal stability (the edge of the thermoregulatory zone) and responses evoked there
- Must provide a "driving function" (i.e. Tc > 40 °C)
- Should examine all of the relevant variables e.g.:
  - System, organ, tissue, cellular, molecular
  - Thermal (Tsk, Tdb, Tau)
  - CV (skin blood flow, CBF, BP)
  - Blood lactate, blood glucose

Individual susceptibility to heat illness

- Environmental conditions
- Body size (mass, skinfold thickness)
  - heat stroke occurs 3.5 times more frequently in excessively overweight young adults than in individuals of average body mass
- State of training / sudden increase in tempo
  - military recruits with low aerobic fitness (>12 mins for 1.5 mile run) and a high body mass index (>26 kg.m^2) have a 9-fold greater risk of heat illness
- Degree of acclimatisation
- Hydration status
- Clothing worn
- State of Health: fever, viral illness, cold, GI disturbances
- Genetic profile: responsiveness to heat
- Genetic disorders: malignant hyperthermia
- Skin disorders - sunburn over 5% of body surface impairs thermoregulation 21d
- Use of medication - diuretics, antihistamines
- Sweat gland dysfunction (e.g. prickly heat)
- Salt depletion
- Age



Cooling equipment & approximate powers



40-75W

200-350W

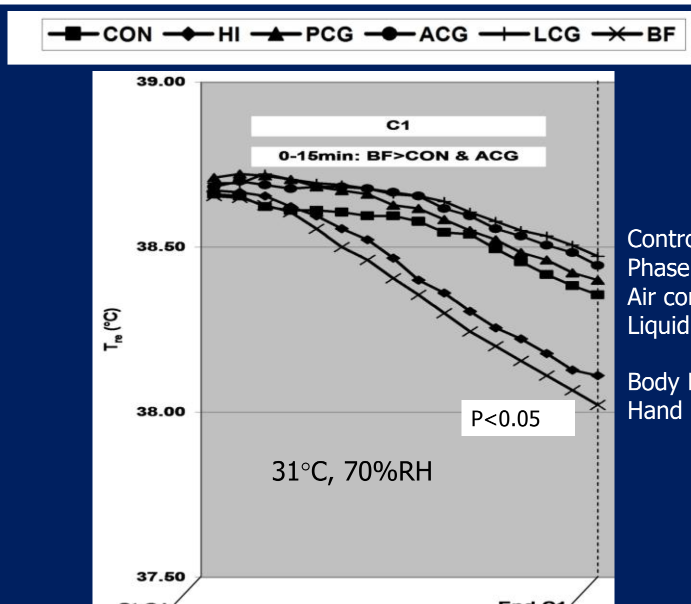
200W

350+W

300W

300W

30W



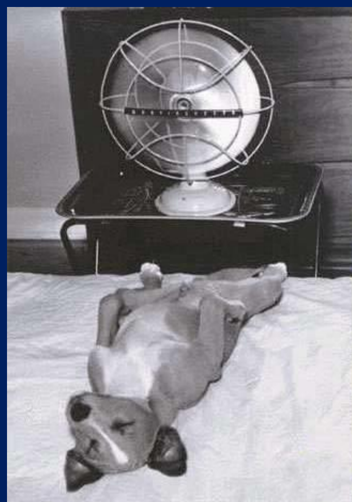
Control
Phase change
Air condition
Liquid condition

Body Fanning
Hand immersion

Mean Tre changes across 15 min of cooling post-exercise (*n*=9).

Barwood, Davey, House & Tipton (2009)

Summary: Best (fastest) Cooling techniques



Naked/Lightly clothed

Heavily clothed

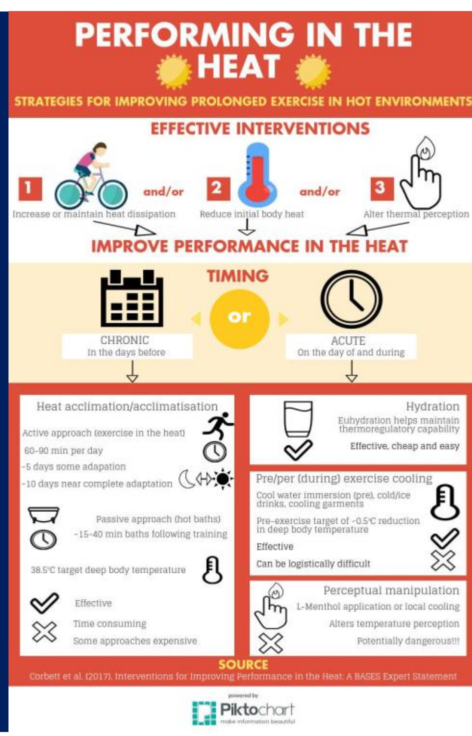
Changes with Acclimatisation

- Improved salt balance
- Increased sensitivity to aldosterone
- Greater CV stability

- Better thermoregulation
- Lower skin and deep body
- Improved work capacity
- Carbohydrate sparing

FACTORS TO CONSIDER AS PART OF A RISK ASSESSMENT FOR THE PROVISION OF IMMERSION SUITS/PFDs IN WINDFARMS

- What are the upper permissible limits of your transfer operations in terms of sea state?
- Is there a procedure in place that eradicates the possibility of someone falling into the water?
- Are the risks of entering the water greater during transfer to the turbine than transfer to the vessel from the quay?
- If yes, could they arrive in the water having suffered some form of trauma (e.g. head injury causing loss of consciousness)?
- What is the maximum time someone could remain in the water (consider worst case scenarios)?
- What is the age/fitness of those likely to fall into the water? Does your organisation have a minimum fitness standard?
- What PPE do you currently provide?
- Does the PPE provided function as an integrated system?
- How long do individuals have to spend exercising (transferring, climbing) in PPE or wearing the PPE fully secured over the course of a day?
- Do you have fluid replacement/hydration policies for use in warm weather?
- Do you have active cooling systems (e.g. air conditioned vessel cabins) available?
- Are reported heat-related problems associated with using PPE health or comfort-related (complaints about light-headedness or discomfort)?
- Do you have any control options in place e.g. Cooling stations, WBGT monitoring (in general, a measure for each field should suffice)? Policy for the use of IS depending on air and water thermal stress levels? Reducing the number of transfers when environmental stress exceeds a given value? Rehydration policy?



Summary: Protection in the Heat

- Environmental assessment
- Personnel selection
- Ensure acclimatisation
- Ensure good hydration
- Appropriate clothing
- Active cooling - pre, during and post exposure
  - Technological solutions are not always the best approach
  - Where possible, use technology to enhance physiological processes of heat loss rather than try and overwhelm them

Thanks