Running in Extreme Environments

Professor Mike Tipton
MBE, MSc, PhD, FPhysiol

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)

PATHOPHYSIOLOGY

COLD AIR
- PERIPHERAL COOLING
- DEEP BODY COOLING
  - HYPOTHERMIA
- PHYSICAL INCAPACITATION
- DEHYDRATION
- FROSTBITE
- NON-FREEZING COLD INJURY
- COLD BURN INJURY
- SNOW BLINDNESS

COLD WATER
- DROWNING
- CARDIAC ARREST
- HYPOTHERMIA
- CIRCUM-RESCUE COLLAPSE

GENGHIS KHAN ICE MARATHON: PREPARATION, STRATEGY AND THE EFFECT OF EXERCISE IN AN EXTREME COLD ENVIRONMENT IN A GROUP OF EXPERIENCED ULTRARUNNERS

2017

- Jan 2016, mountains of the Terelj National Park, Mongolia, Ta -35 °C
- Multinational group of experienced ultrarunners (n=9, male 5, 25–53 y)
- Concerns about safety in a remote environment were universal
- Consensus regarding clothing, equipment, hydration and nutrition
- The race was completed in 3:05–5:50. No significant difficulties:
  - Freezing around the nostrils and irritated the airways
  - No cold-induced bronchospasm
  - No cases of hypothermia
  - Two cases of frostbite; earlobe (moderate) and nose (mild)
  - No DOMs

Risk factors for hypothermia

Cold air/water temperature	
Air/water movement	Faster moving fluids increase convective heat loss
Age	Children and small adults cool faster than large adults due to their lower levels of subcutaneous fat and higher surface area to mass ratio
Body stature	Tall thin individuals cool faster than short stocky people
Body morphology	Body fat and unperfused muscle are good insulators
Gender	Females tend to have more subcutaneous fat than men
Fitness	High fitness enables higher heat production
Nutrition/Fatigue/Injury	Hypoglycaemia attenuates shivering, Injury and Exhaustion reduce heat production – all three increase cooling
Intoxication	Drug or alcohol depressant effects on metabolism
Lack of appropriate clothing	Insulation without wind proofing or vice versa

Rewarming

Mild hypothermia
- Warm sweet drink and external heat applied to speed thermal comfort
- External active rewarming *e.g.* hot air or water-circulating blanket, hot packs, hot bath

Severe hypothermia
- Regard as critically ill, handle as little and as gently as possible
  - Risk of VF is increased in a cold myocardium and can be precipitated by movement, CPR, insertion of a supraglottic airway or tracheal intubation
- In cases of out-of-hospital moderate and severe hypothermia, passive rewarming is the safest way to rewarm (insulate and allow the casualty's metabolism to rewarm then slowly ~ 0.75 to 1.0 °C per hour)

- Extracorporeal life support (ECLS), including cardiopulmonary bypass and extracorporeal blood warming and oxygenation (ECMO), has revolutionised the management of hypothermic cardiac arrest

(Neilsen et al. 1992; Handley et al. 1992)

Cooling of Superficial Nerves and Muscles

- Maximum power output falls by 3% per °C fall in muscle temperature
- Below T_{local} of 20°C: rate of conduction and amplitude of action potentials is slowed
- Physical incapacitation at a Tm of 27 °C

Clarke et al (1958);
Vincent & Tipton (1988)

Limitations to aerobic exercise performance and VO_{2max} in the cold

- Lower Tdb, Tm & Tsk
- Increased lactate
- Lower glucose levels
- Increased VO_2/reduced economy
- Reduced HR_{max}
- Lower cardiac output

Skin blood flow responses

From: Rowell L B. *Human circulation.* Regulation during physical stress. OUP, 1986.

Risk factors for cold injuries:

Physiological	Medical
Ethnicity (Afro-Caribbean descent)	
Age	Hypotension
Sex (Women)	Atherosclerosis
Hypothermia	Arteritis
Prior NFCI	Raynaud's Disease
Trauma	Vasospastic disorders
Erythrodermas	Anaemia
Hyperhidrosis	Sickle cell disease
Hypoxia	Diabetes
Smoking	Shock
Energy depletion	Vasoconstrictors
Poor physical conditioning	

Policies associated with the prevention of cold injures

- Physiology & Behaviour
  - Promoting peripheral blood flow: maintaining peripheral temperatures
  - Recognition of early signs of injury: early intervention
  - Best practice in the field: care of the extremities, diet, hydration etc
- Recognition of predisposing factors
  - Selection: excluding those at risk
  - Environmental threat - decision making tools: Avoidance
- Technical / Equipment
  - Appropriate equipment, clothing: design; fit; materials; evaluation

Based on: Montgomery, Tipton, Dhillon et al (2013)

Out of Hospital Treatment

Frostbite

- Shelter
- Frostnip – rewarm 10 min (armpit)
- Superficial/deep frostbite: EVACUATE
- Prevent further cooling
- Rewarm only if:
  - Re-exposure unlikely
  - Further trauma unlikely
  - Follow-up treatment available
- Rewarming
  - Do not rub injured part
  - Whirlpool bath + antiseptic maintain at 38 °C for 15-60 min until red/purple colour and tissues pliable, expose to warm air
  - Topical aloe vera cream/gel (anti-prostaglandin agent), loose protective dressing
  - Aspirin, Ibuprofen

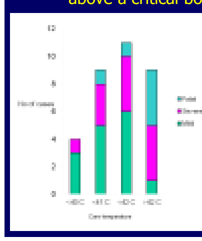
NFCI

- Shelter
- Carefully remove boots & socks
- Slightly elevate the limb
- Rewarming
  - Insulate area do not rewarm rapidly
  - Slowly, by exposure to warm air alone (no immersion)
  - Encourage movement of toes & ankles
  - Painful: Amitriptyline (10–75 mg in a single dose at night) - weak evidence-base
- Severe cases (tissue damage) 2x daily cleansing with dilute antibacterial preparation
- Photograph tissue damage
- Prevent damage to skin

Direct effect of heat

WARNING SIGNS OF HEAT DISORDERS

Severity of EHI related to the cumulative time above a critical body temperature



- Severity increases with cumulative time above a critical (but ill-defined) threshold temperature
- Trec essential for diagnosis - adherence to a set threshold is misleading
- Early and rapid cooling is ESSENTIAL

(Shapiro & Seidman, 1990)

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) 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

Tipton (2015)

- Competition changes the relationship between perceived and actual thermophysiological state
- It alters behavioural thermoregulation and increases thermophysiological strain - this could increase the risk of heat-illness
- Psychophysiological and psychological measures may identify susceptible individuals

Indirect effect of heat

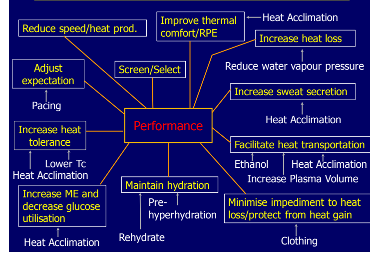
Performance Impairment with Heat Stress

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)

Heat: Mitigation

Minimising performance impairment in the heat

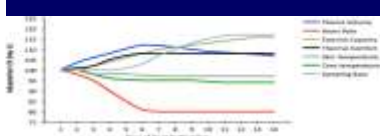


Acclimatisation to Heat: Methods

- The exposures can be:
  - In the field (acclimatisation)
  - In a suitable climatic chamber (acclimation)
  - Using sweat suits (impermeable/semi-permeable clothing) or saunas - partially effective
  - Passive (e.g. hot bath) – partially effective
  - With exercise
    - Constant work
    - Self-paced work
    - Controlled hyperthermia

Acclimatisation to Heat: Summary

- Raise body temperature; Stimulate sweating
- Representative temperatures (30-35°C, 100min per day)
- Exercise during exposures (mode unimportant, intermittent exercise OK)
- Acclimatisation: specific to WBGT & activity level
- 10-14 days, no more than 3 days between exposures. 66-75% changes in 4-6d
- Fitter: acclimatise more quickly (7-10 days), still need to exercise in heat
- Return to a temperate climate: major benefits retained 1 week, 75% are then lost within 3 weeks



HA Update – last 5 years

- Performance (TT, VO_{2max}, power output, lactate, PV, Q_{max}) may be improved in cool conditions (13 °C) following HA, but this is unaffected by an additional hypoxic stressor (Lorenzo *et al.* 2010; Rendell *et al.* 2017)
- Short term heat acclimation (5 x 90 min, Tc 38.5) with permissive dehydration has been shown to effectively induce HA (PV, HR, Tc, Rowing performance) (Garrett *et al.* 2014)
- But, when thermal-strain is matched, permissive dehydration which induces a mild, transient, hypohydration does not affect the acquisition and decay of HA, or endurance performance parameters (Neal *et al.* 2016)
- A separate moderate overnight normobaric hypoxic-stimulus does not affect the time-course or magnitude of HA (Rendell *et al.* 2017)
- Individual variation: HA indices are mainly independent, 'low' or 'high' responders on one index do not necessarily demonstrate similar response across other indices (Corbett *et al.* 2018)

Hand Cooling: Athens 2004, Beijing 2008, Rio 2016, Tokyo 2020

Sir Chris Hoy

Sir Bradley Wiggins

Thank you

https://www.researchgate.net/profile/Mike_Tipton
@profmiketipton
michael.tipton@port.ac.uk