Exercise in Hot Environments

Victorian Views of Heat Exposure

- Europeans were not “designed” to survive in hot climates
  - employ “men of color” for troops in India
  - women particularly are vulnerable to reproductive disorders
  - “red underwear” to protect against dangerous effects of the sun

“Actinic Rays”

- Sunlight has dangerous rays the penetrate the skull and cause solar apoplexy
  - “spine pads made of quilted cloth interwoven with a red material..”
  - “an enormous topee to which was attached a long purple scarf..Under this a spreading spine pad made of kongoni hide lined with red flannel… black goggles and a huge stripped umbrella” *Elspeth Huxley*
  - Is this why British uniforms were bright red???

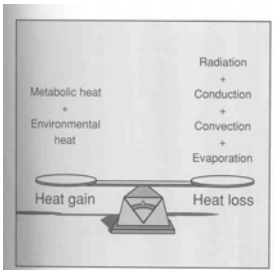
Unique features of human thermoregulation

- *Homo sapiens* evolved in a tropical climate
  - a homeotherm (birds and mammals)
  - importance of evaporative cooling
    - no selective brain cooling? *(rete mirabile)*
    - No panting
    - symp cholinergic sweat glands
    - one of the highest sweat rates of any mammal
    - lack of fur/ skin is the main organ for thermoreg.
  - active vasodilation
  - importance of behavioral cooling

Behavioral Cooling

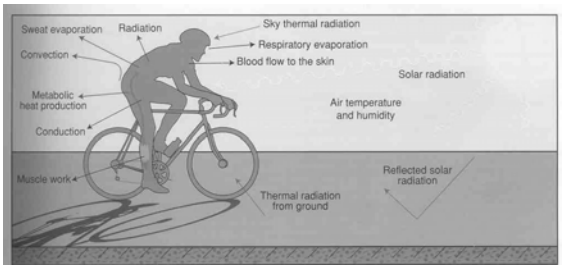
- When Ta is hotter than Tsk
  - cover up
  - loose fitting
  - black?
  - rest in the day

Physics of Heat Exchange



$S = M \pm R \pm C \pm D - E$

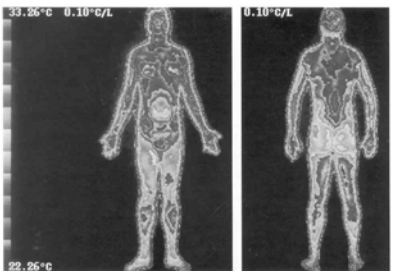
Exercise & Heat Balance



Heat exchange at rest and exercise

Mechanisms of Heat Loss	Rest		Exercise (70% VO2max)	
	% total	Kcal/min	% total	Kcal/min
C + D	20	0.3	15	2.2
R	60	0.9	5	0.8
E	20	0.3	80	12.0

Core and Shell Temperature



Core Temperature

- Measurement Sites
- Rectal
- Esophageal
- tympanic
- Ear canal
- oral
- axillary
- intestinal

- Measurement Response

- steady state
- transient changes
- during exercise
- during fluid intake

Skin Temperature

- Number of measurement sites (3-15)
- "Weight" of measurement sites
- Uncovered thermistor or thermocouple

- $T_{sk} = 0.3T_{ch} + 0.3T_{arm} + 0.2T_{thigh} + 0.2T_{calf}$

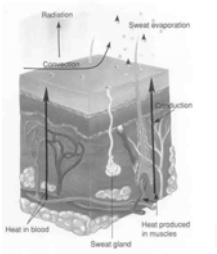
Ramanathan formula

Mean Body Temperature

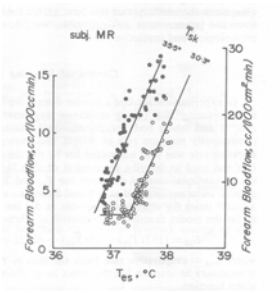
- Tb = (0.4 Tsk) + (0.6 Tcore)
- Heat content of the body = HC
  - total calories of heat contained in the body tissues
  - specific heat of body tissues is 0.83 kcal/kg/^{o}C (amt of heat to raise temp 1^{o}C)
- HC = 0.83 (Wt x Tb)

Vasodilation

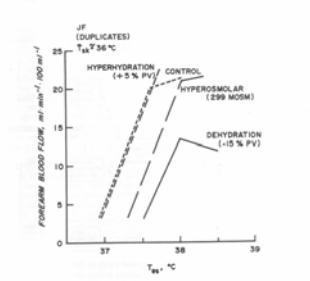
- Humans have 2 methods to increase skin blood flow
  - release symp vc tone
  - active symp vasodilation
- Active vasodilation is activated by
  - rise in core temp
  - rise in local sk temp
  - rise in mean sk temp
- Vasodilation is opposed by
  - baroreceptors
  - osmoreceptors



Effect of T_a on FBF

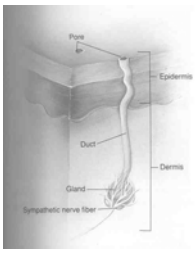


Effect of hydration on FBF



Sweating

- Apocrine & eccrine sweat glands
- neural control
  - symp cholinergic
  - symp adrenergic
- hormonal control
  - epinephrine
  - aldosterone
  - ADH
- increase size of glands



Fluid is filtered from plasma
Electrolytes are actively reabsorbed

Evaporation of Sweat

- Insensible perspiration (20% of heat loss at rest)
  - surface of the skin
  - respiratory tract
- Sensible perspiration
  - sweating from the eccrine glands
  - 2-4 million sweat glands
  - each liter of sweat extracts 580 kcal of heat from the body
  - sweat is dilute (0.2 to 0.4% NaCl)

Sweating facts

- Sweat must evaporate to remove heat
  - men are “wasteful sweaters”?
  - humidity increases sweat drippage
  - in a hot humid environment, drying the skin will increase evaporation
  - person’s with a greater SA will lose more heat by evaporation

Sweat Sensitivity

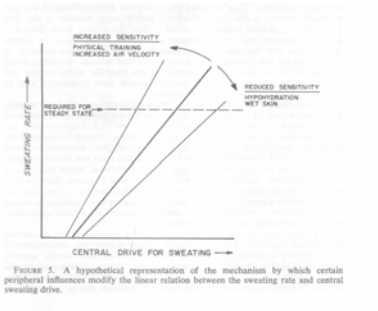
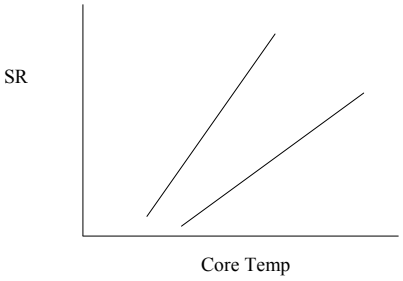


FIGURE 5. A hypothetical representation of the mechanism by which certain peripheral influences modify the linear relation between the sweating rate and central sweating drive.

Effect of heat acclimation



Set Point Theory

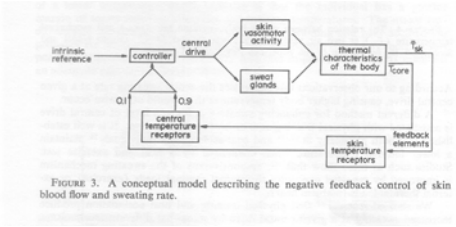
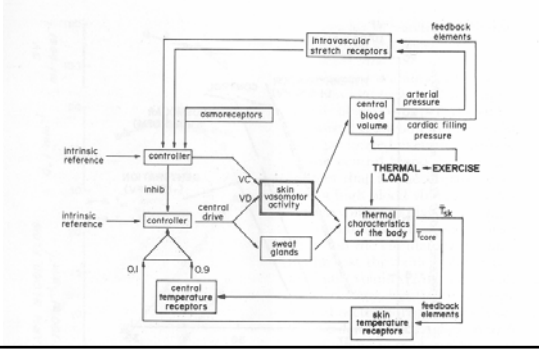


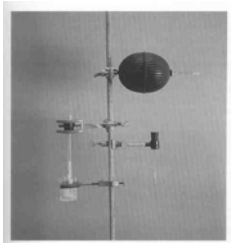
FIGURE 3. A conceptual model describing the negative feedback control of skin blood flow and sweating rate.

- Fever is an upward shift in the set point
- pyrogenic substances (resp to/from bacteria) stimulate synthesis of prostaglandins by the brain.

Non-thermal factors



Measuring Heat Stress



WBGT

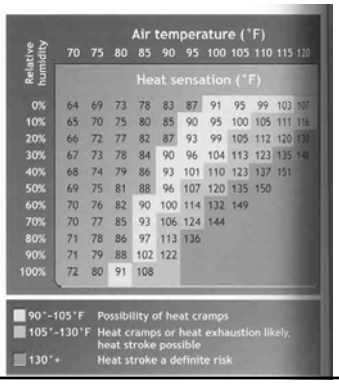
80-84 Use discretion

85-87 Avoid strenuous activity

>88 Avoid exercise training

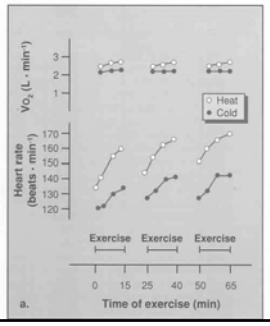
- WBGT = 0.1 (Tdb) + 0.7 (Twb) + 0.2 (Tg)

Heat Stress Index



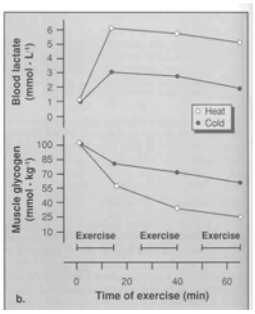
Exercise Responses in the Heat

- heat ↑ VO2 only slightly
- Heat ↑ HR greatly



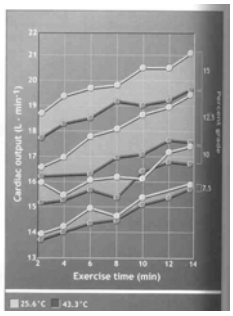
Exercise in heat, cont.

- Heat increases use of glycogen
- heat increases lactate production

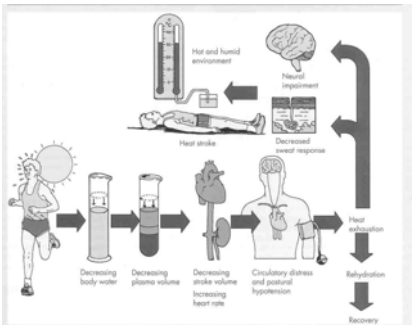


Exercise in Heat, cont.

- The effect of heat on cardiac output and HR response depends on
  - ambient temp.
  - exercise intensity



Path to heat Illnesses



Heat Illnesses

- Prickly heat
  - inflammation of the sweat glands
- Heat cramps
  - cramping of muscles
    - electrolyte imbalance
    - accumulation of fluid in muscle cells
- Heat exhaustion
  - heat production > heat loss
    - Tc < 39°C, dehydrated, unfit, unacclimatized

Heat Stroke

- 1917, finally recognized as a failure of thermoregulation
- life threatening condition
  - U.S., 250 deaths/yr)
- Tc > 40°C
- cessation of sweating?
- confusion
  - tissue damage, elevated enzymes

Heat Illness Warning signs

- Heat Exhaustion
  - headache, tingling
  - chills, shivering
  - great fatigue
  - pale, moist, cool skin
  - dizziness
  - rapid, weak pulse
  - vomiting, nausea
  - dehydration
- Heat Stroke
  - headache
  - unconsciousness
  - confusion
  - bizarre behavior
  - hot, red skin
  - rapid, strong pulse
  - profuse sweating
  - fainting

Cause of death from heat stroke?

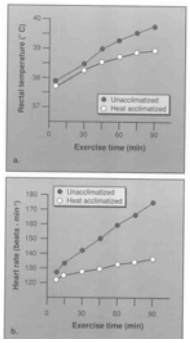
- Survival depends on temp and length of exposure to Tc > 40°C
- Rapid cooling may occur, but death still occurs several days later
- Type of septic shock?
  - Increase in lipopolysaccharides (LPS) from intestinal lumen
  - heat stress injuries the intestinal lining, increasing permeability to LPS

Treatment for Heat Stroke?

- Damage is ~ to length of time spent at core temperature > 44°C
- Ashcroft: most effective method is to sponge victim with tepid water. Evap cooling is more effective than cold water bath--no vasoconstriction. Ice packs
- Armstrong: immersion in cold water is still the best method

Heat Acclimatization

- Habituation with continued daily heat exposures
- Immediate classic signs of heat acclimation
  - lower heart rate
  - increased sweat rate
  - lower skin temperatures
  - lower core temperature



Other signs of heat acclimatization

- Increased plasma volume
- Decreased sweat electrolytes
- Increased sweating sensitivity
- Decreased sweating threshold
- Increased vasodilatory sensitivity
- Decreased vasodilatory threshold
- Reduced muscle glycogen use 50-60%

Time courses

Table 2.2
"Plateau days" of Physiological Adaptations (Point at Which Approximately 95% of the Adaptation Occurs) During Heat Acclimatization

Adaptation	Days of heat acclimatization
	1 2 3 4 5 6 7 8 9 10 11 12 13 14
Heart rate decrease	
Plasma volume expansion	
Rectal temperature decrease	
Perceived exertion decrease	
Sweat Na^+ and Cl^- concentration decrease*	
Sweat rate increase	
Renal Na^+ and Cl^- concentration decrease	

* While consuming a diet low in NaCl.
Reprinted from Armstrong and Dziados 1986.

How do you acclimatize?

- Exercise daily for at least 14 days
  - > 50% VO_2max
  - work up to 90 to 100 min
  - keep hydrated (replace sweat losses)
  - replace sodium loss with meals

The Camel: master of heat tolerance in the desert

- Homeotherm, but
  - Tb varies by 7°
  - heat loss by R, less E
  - lower brain temp/cc in nose and brain
  - kidneys
  - coat (18°C gradient)
  - alimentary tract water storage (10-20% body wt)
  - RBC osmotic fragility
  - drinking (100l in 10 min)
  - behavioral

- tolerates > 25% loss of body wt with only ~ 10% loss of PV