Energy metabolism, thermoregulation

The maintenance of a particular temperature in a living body.

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Overview of Thermoregulation

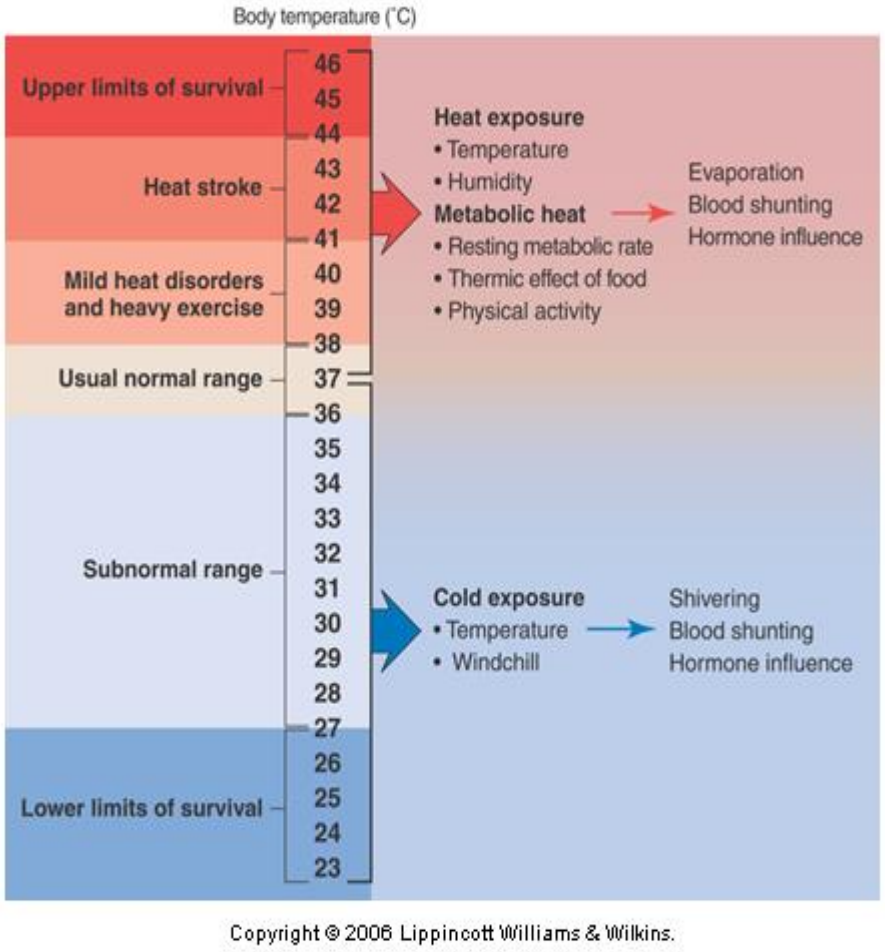
- Mechanisms of Thermoregulation
- Exercise in Heat Stress
- Heat Illness
- Exercise in Cold Stress

Thermal Balance

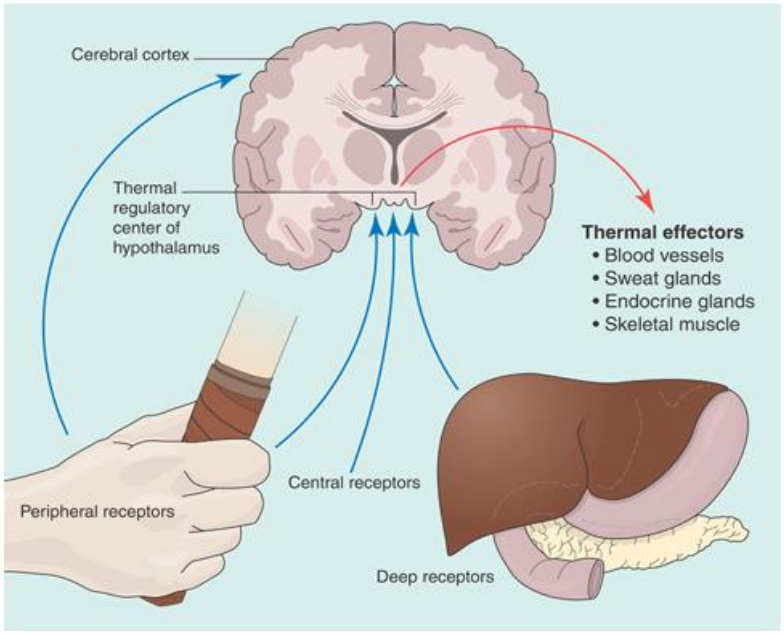
- Core temperature (T_{CO}) is in dynamic equilibrium as a result of balance between heat gain and heat loss.
- Mean body temperature (T_{body}) represents an average of skin and internal temperatures.

Hypothalamus Regulation of Temperature

- Hypothalamus acts as “thermostat” that makes thermoregulatory adjustments to deviations from temperature norm in the brain (37☜ C ± 1☜ C or 98.6☜±1.8☜ F).



Hypothalamus Regulation of Temperature

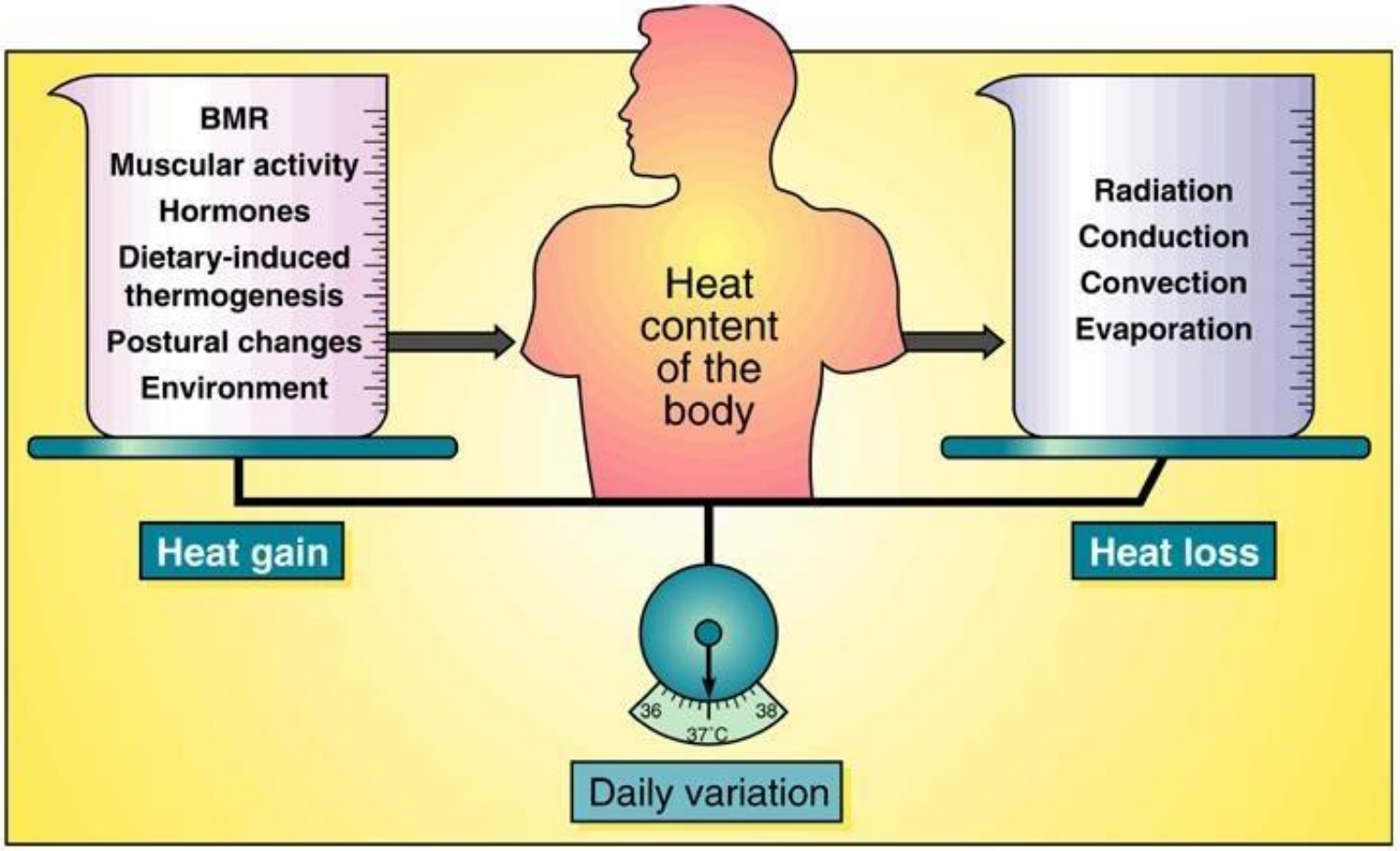


- Mechanisms are activated in two ways:
  - Thermal receptors in skin provide input to central command
  - Direct stimulation of hypothalamus through changes in blood temperature perfusing area

Thermoregulation in Cold

- Vascular adjustments: constrict peripheral blood vessels.
- Muscular activity: exercise energy metabolism and shivering.
- Hormonal output: epinephrine and norepinephrine increase basal heat production; prolonged cold – thyroxin.

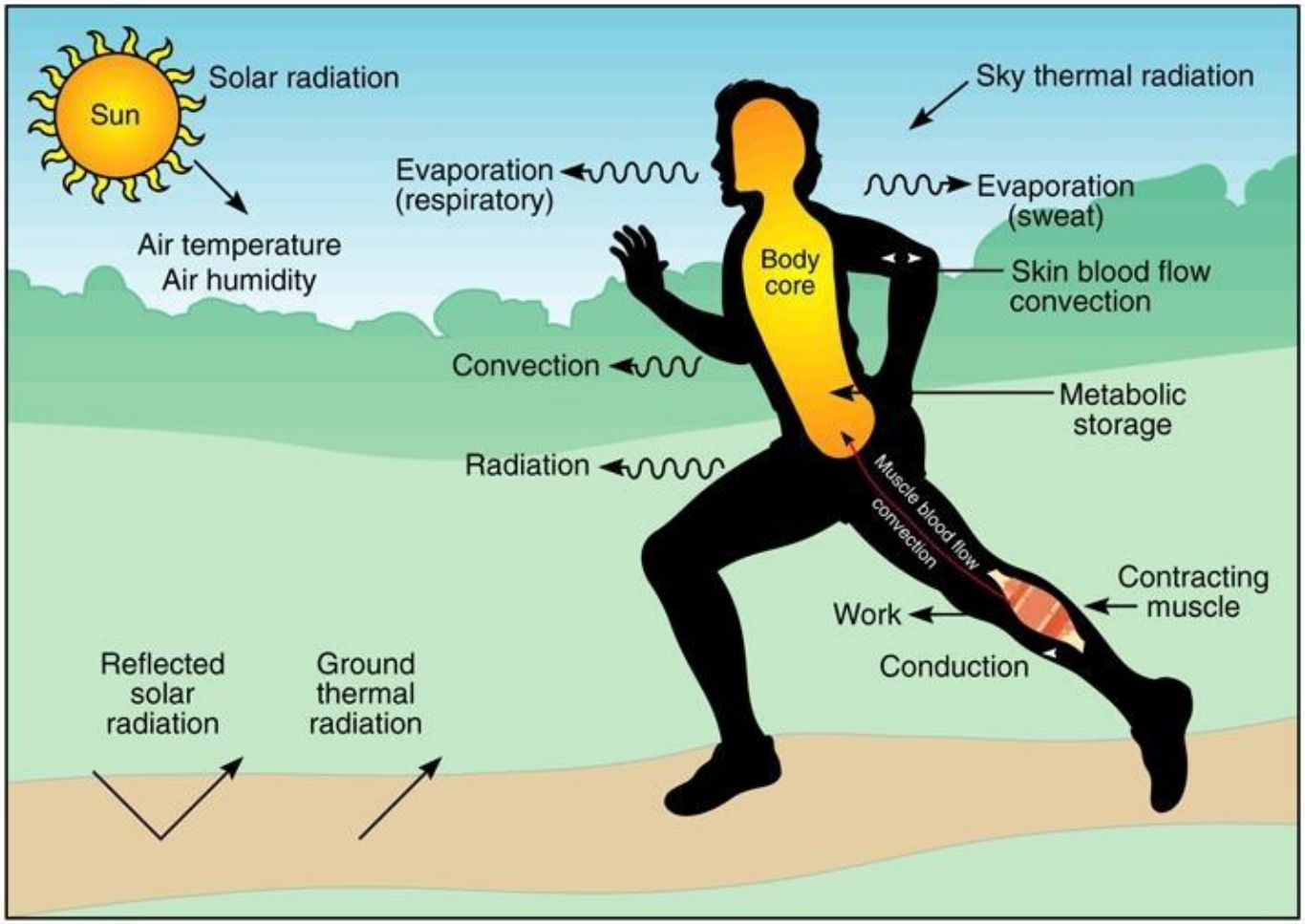
Thermoregulation in Heat



Thermoregulation in Heat

- Heat Loss by Radiation (~ 10%)
  - Objects emit electromagnetic heat waves without molecular contact with warmer objects.
  - When temperature of things in environment exceeds the skin temperature, radiant heat energy is absorbed from the surroundings.

Thermoregulation



Thermoregulation in Heat

- Heat Loss by Conduction
  - Direct transfer of heat through a liquid, solid, or gas from one molecule to another.
  - A small amount of body heat moves by conduction directly through deep tissues to cooler surface. Heat loss involves the warming of air molecules and cooler surfaces in contact with the skin.
  - The rate of conductive heat loss depends on thermal gradient.

Thermoregulation in Heat

- Heat Loss by Convection (+ conduction 35%)
  - Effectiveness depends on how rapidly the air (or water) adjacent to the body is exchanged.
  - Air currents at 4 mph are about twice as effective for cooling air currents at 1 mph.

Thermoregulation in Heat

- Heat Loss by Evaporation (~ 55%)
  - Heat transferred as water is vaporized from respiratory passages and skin surfaces.
  - For each liter of water vaporized, 580 kcal transferred to the environment.
  - When sweat comes in contact with the skin, a cooling effect occurs as sweat evaporates.
  - The cooled skin serves to cool the blood.

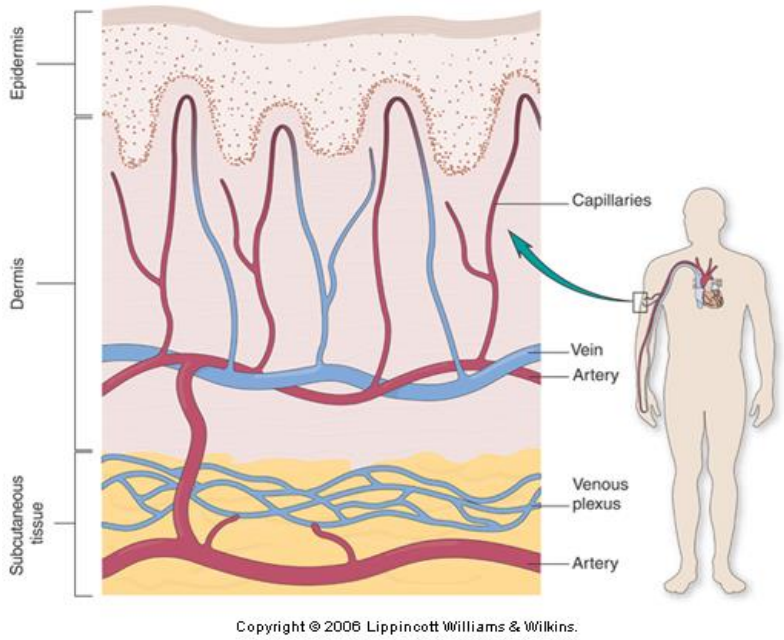
Heat Loss at High Ambient Temperatures

- Effectiveness of heat loss via conduction, convection, and radiation decreases.
- When ambient temperature exceeds body temperature, heat is gained.
- The only effective mechanism is evaporation of sweat and respiratory tract vaporization of water.

Heat Loss in High Humidity

- Total sweat vaporized from skin depends on:
  - Surface area exposed to environment
  - Temperature and humidity of ambient air
  - Convective air currents about the body
- Most important factor is relative humidity.
- When relative humidity is high, the ambient water vapor pressure approaches that of the moist skin and evaporation is impeded.

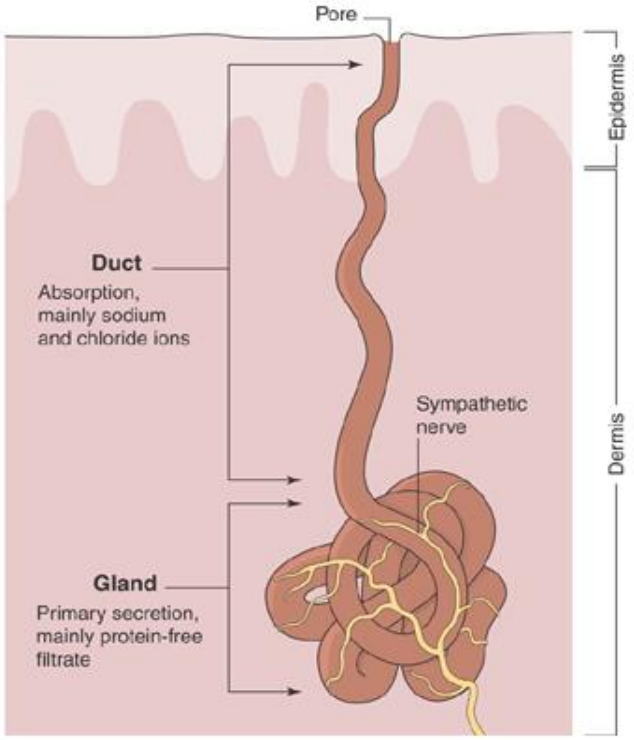
Integration of Heat-Dissipating Mechanisms



- Circulation: Superficial venous and arterial blood vessels dilate to divert warm blood to the body shell.

Integration of Heat-Dissipating Mechanisms

- Evaporation. Sweating begins within 1.5 s after start of vigorous exercise.
- Hormonal adjustments. Certain hormonal adjustments are initiated in heat stress as body attempts to conserve fluids and sodium.



Hormones in Heat Stress

- Antidiuretic hormone (ADH) is released to increase water re-absorption from kidneys.
- Aldosterone is released to increase the re-absorption of sodium.

Effects of Clothing

Cold Weather Clothing

provide an air barrier to prevent convection and conduction.

- Layers provide more trapped air
- Allow water vapor to escape

Warm Weather Clothing

loose fitting to permit free convection.

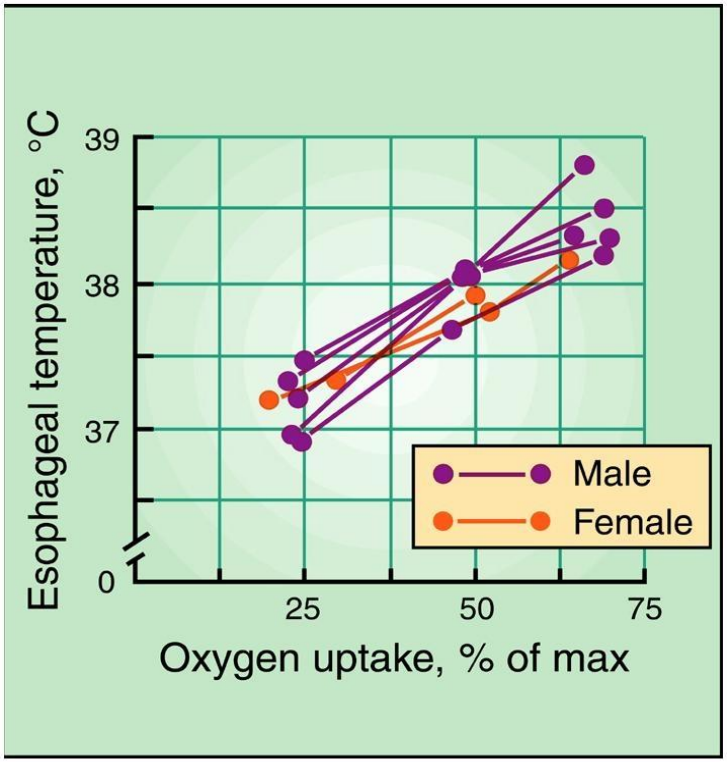
- The less surface covered the more evaporative cooling.
- Clothing should be loosely woven to allow skin to breathe.

Exercise in Heat Stress

- Circulatory Adjustments.
  - Cardiovascular drift – fluid loss reduces plasma volume (about 10% of fluid lost comes from plasma. About 50% comes from intracellular water).
  - Visceral vascular constriction and skin & muscle vascular dilation.
  - Maintaining blood pressure. Circulatory regulation and maintenance of muscle blood flow take precedence over temperature regulation often at the expense of spiraling core temperature during exercise in heat.

Exercise in Heat Stress

- Core temperature
  - More than likely a modest increase in core temperature reflects favorable internal adjustments.



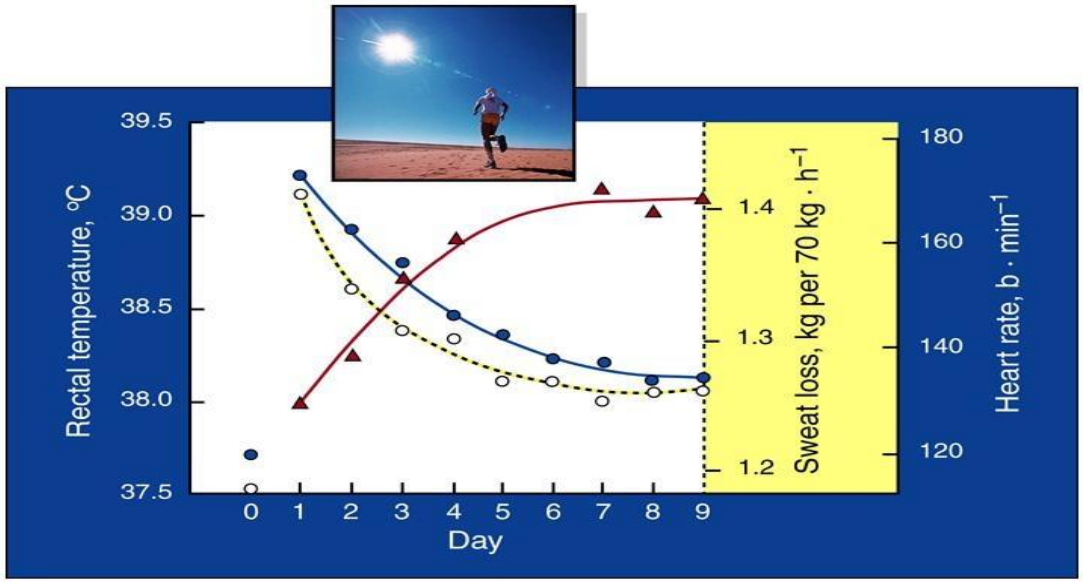
Water Loss in the Heat

- Magnitude of Fluid Loss in Exercise.
- Consequences of Dehydration.
  - ↓plasma volume ⌛ ↓ peripheral blood flow & ↓sweat rate
- Water Replacement
  - Primary aim of fluid replacement during exercise is to maintain plasma volume
  - The most effective defense against heat stress is adequate hydration
- Electrolyte Replacement.

Acclimatization to Heat

Acclimatization refers to physiological changes that improve heat tolerance.

2 – 4 hours daily heat exposure produce complete acclimatization 5-10 days.



o Rectal temperature
• HR
Δ Sweat rate

Factors that Improve Heat Tolerance: Acclimatization

Improved cutaneous blood flow	Transports metabolic heat from deep tissues to body's shell
Effective distribution of cardiac output	Appropriate circulation to skin & muscles to meet demands.
Lowered threshold for start of sweating	Evaporative cooling begins early in exercise.
More effective distribution of sweat over skin surface	Optimum use of surface for effective evaporative cooling.
Increased rate of sweating	Maximize evaporative cooling.
Decreased salt concentration of sweat	Dilute sweat preserves electrolyte in fluids.

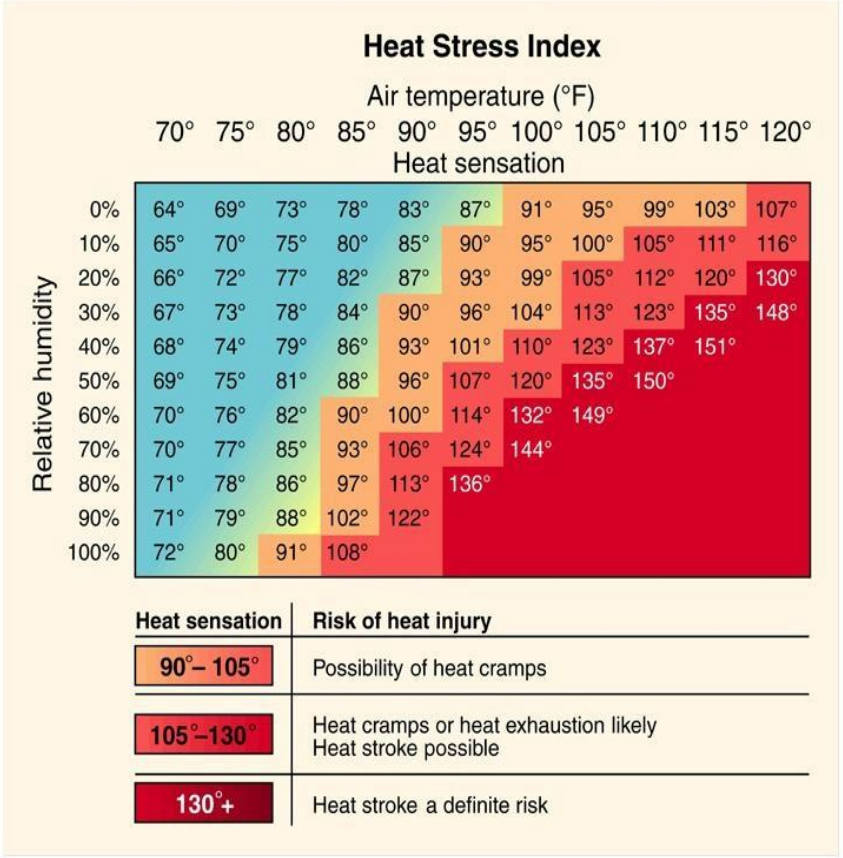
Factors that Improve Heat Tolerance

- Fitness Level
- Age (see FYI)

  Aging delays the onset of sweating and blunts the magnitude of sweating response
- Gender
- Body fatness

Evaluating Heat Stress

- Prevention remains most effective way to manage heat-stress injuries
- *Wet bulb-globe temperature* relies on ambient temperature, relative humidity, and radiant heat.
- Heat stress index



Heat Illness

Increasing Severity

Heat Disorder	Heat Cramps	Heat Syncope	Heat Exhaustion	Heat Stroke
Warning Signs	Muscle pain Muscle spasms Muscle cramps	Fatigue Dizziness Weakness Thirst Profuse sweating Faintness	Fatigue Dizziness Weakness Thirst Profuse sweating Pale, cool skin Headache Nausea Chills Faintness Unconsciousness Vomiting Diarrhea	Headache Nausea Chills Unconsciousness Hot, dry skin Cease sweating Fast, shallow heart rate Vomiting Diarrhea Seizures Coma
Remedy	Consume large amounts of fluids and replace electrolytes	Stop exercise Move to shade Consume fluids	Stop exercise Move to cool place Administer fluids	First aid

Heat Illness

Table 1 Heat Illness: Causes, Signs and Symptoms, and Prevention

CONDITION	CAUSES	SIGNS AND SYMPTOMS	PREVENTION
Heat Cramps	Intense, prolonged exercise in the heat	Tightening, cramps, involuntary spasms of active muscles; low serum Na^+	Cease exercise; rehydrate
Heat Syncope	Peripheal vasodilatation and pooling of venous blood; hypotension; hypohydration	Lightheadedness; syncope, mostly in upright position during rest or exercise; pallor; high rectal temperature	Ensure acclimatization and fluid replenishment; reduce exertion on hot days; avoid standing
Heat Exhaustion	Cumulative negative water balance	Exhaustion; hypohydration, flushed skin; reduced sweating in extreme dehydration syncope, high rectal temperature	Proper hydration before exercise and adequate replenishment during exercise; ensure acclimatization
Heat Stroke	Extreme hyperthermia leads to thermoregulatory failure; aggravated by dehydration	Acute medical emergency; includes hyperpyrexia (rectal temperature >41°C, 105.8°F); lack of sweating and neurologic deficit (disorientation, twitching, seizures, coma)	Ensure acclimatization; identify and exclude individuals at risk; adapt activities to climatic constraints

Prevention of Heat Illness

- Allow adequate time for acclimatization.
- Exercise during cooler parts of day.
- Limit/defer exercise if heat stress index is in high risk zone.
- Hydrate properly prior to exercise and replace fluid loss during and after exercise.
- Wear clothing that is light in color and loose fitting.

Exercise in the Cold

Table 15.5 Core Temperature and Associated Psychological Changes That Occur as Core Temperature Falls; Individuals Respond Differently at Each Level of Core Temperature

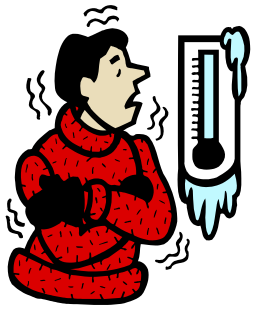
	CORE TEMPERATURE		
STAGE	°F	°C	PHYSIOLOGICAL CHANGES
Normothermia	98.6	37.0	
Mild Hypothermia	95.0	35.0	Maximal shivering, increased blood pressure
	93.2	34.0	Amnesia; dysarthria; poor judgment; behavior change
	91.4	33.0	Ataxia; apathy
Moderate Hypothermia	89.6	32.0	Stupor
	87.8	31.0	Shivering ceases; pupils dilate
	85.2	30.0	Cardiac arrhythmias; decreased cardiac output
	85.2	29.0	Unconsciousness
Severe Hypothermia	82.4	28.0	Ventricular fibrillation likely; hypoventilation
	80.6	27.0	Loss of reflexes and voluntary motion
	78.8	26.0	Acid–base disturbances; no response to pain
	77.0	25.0	Reduced cerebral blood flow
	75.2	24.0	Hypotension; bradycardia; pulmonary edema
	73.4	23.0	No corneal reflexes; areflexia
	66.2	19.0	Electroencephalographic silence
	64.4	18.0	Asystole
	59.2	15.2	Lowest infant survival from accidental hypothermia
	56.7	13.7	Lowest adult survival from accidental hypothermia

From American College of Sports Medicine position stand. Prevention of cold injuries during exercise. *Med. Sci. Sports Exerc.*, 38:2012, 2007.

- Cold strain
  - Exposure to cold produces physiological & psychological challenges
  - Body fat differences effect physiological function in cold
- Acclimatization to the Cold

  Humans adapt more successfully to chronic heat than cold exposure.

Exercise in the Cold



- Evaluating Environmental Cold Stress
  - Wind chill index
- Respiratory tract in Cold
  - Cold air does not damage respiratory passages.
  - Air warms to between 80° F to 90° F as it reaches bronchi.
  - Humidification of inspired cold air produces water & heat loss from respiratory tract.

Wind speed, mph	Ambient temperature, °F*															
	40	35	30	25	20	15	10	5	0	−5	−10	−15	−20	−25	−30	
	Equivalent temperature, F															
Calm	40	35	30	25	20	15	10	5	0	−5	−10	−15	−20	−25	−30	Calm
5	37	33	27	21	16	12	6	1	−5	−11	−15	−20	−26	−31	−35	5
10	28	21	16	9	4	−2	−9	−15	−21	−27	−33	−38	−46	−52	−58	10
15	22	16	11	1	−5	−11	−18	−25	−36	−40	−45	−51	−58	−65	−70	15
20	18	12	3	−4	−10	−17	−25	−32	−39	−46	−53	−60	−67	−76	−81	20
25	16	7	0	−7	−15	−22	−29	−37	−44	−52	−59	−67	−74	−83	−89	25
30	13	5	−2	−11	−18	−26	−33	−41	−48	−56	−63	−70	−79	−87	−94	30
35	11	3	−4	−13	−20	−27	−35	−43	−49	−60	−67	−72	−82	−90	−98	35
**40	10	1	−6	−15	−21	−29	−37	−45	−53	−62	−69	−76	−85	−94	−101	40**

Little danger Danger Great danger

* °C= 0.556 (°F −32)

** Convective heat loss at wind speeds above 40 mph has little additional effect on body cooling