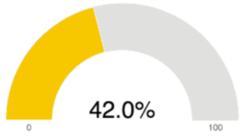
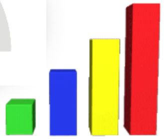
بسم الله الرحمن الرحیم











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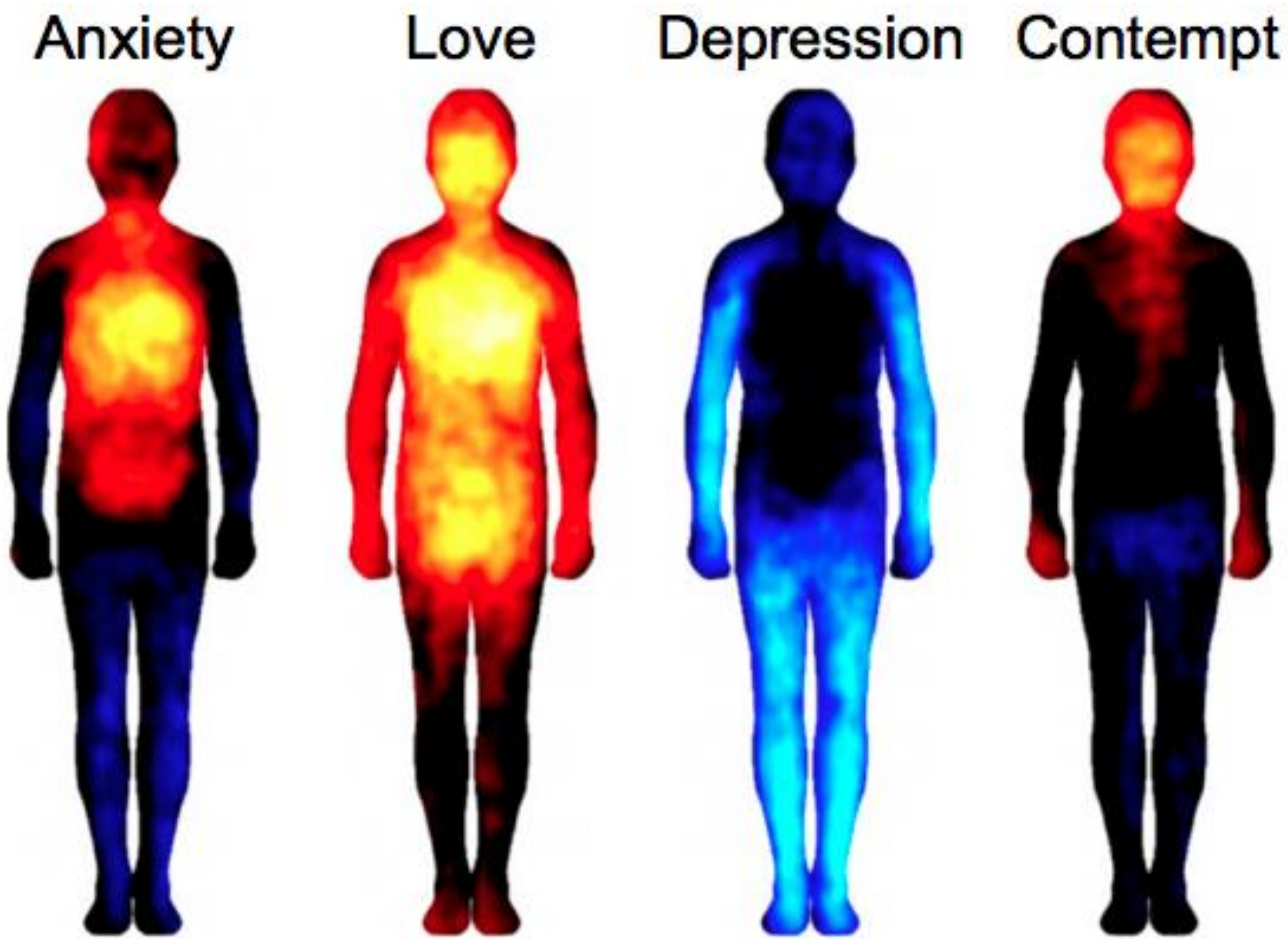
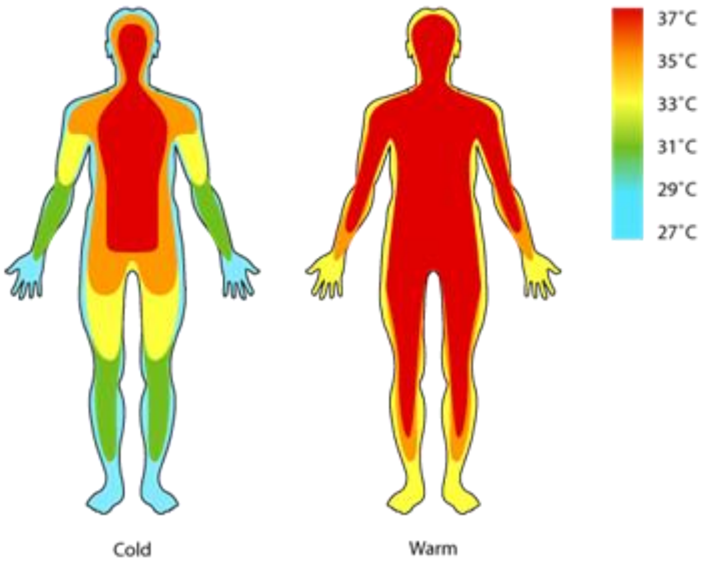
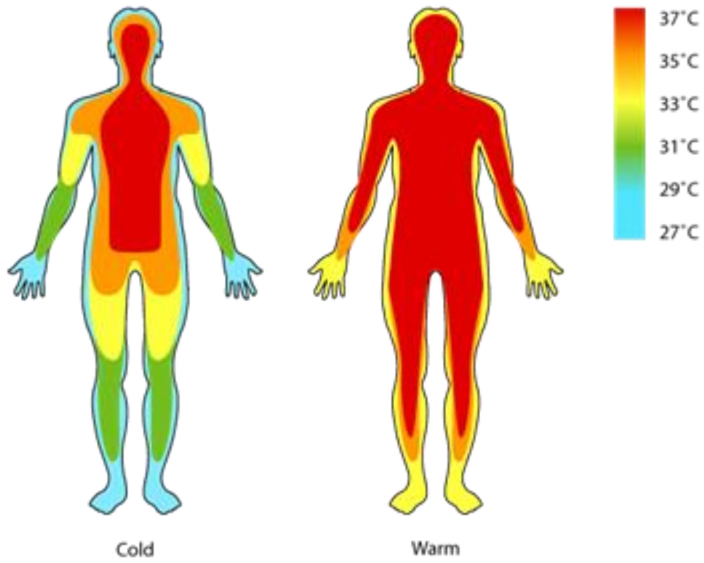

Anxiety
Love
Depression
Contempt

7%



Temperature Regulation



Temperature Regulation

Objectives

1. **Define the term *homeotherm*.**
2. **Present an overview of heat balance during exercise.**
3. **Discuss the concept of "core temperature."**
4. **List the principal means of involuntarily increasing heat production.**
5. **Define four processes by which the body can lose heat during exercise.**
6. **Discuss the role of hypothalamus as the body's thermostat.**

Objectives

7. **Explain the thermal events that occur during exercise in both a cool/moderate and hot/humid environment.**
8. **List physiological adaptations that occur during acclimatization to heat.**
9. **Describe the physiological responses to a cold environment.**
10. **Discuss the physiological changes that occur in response to cold acclimatization.**

An Overview of Heat Balance

- **Humans are homeotherms**
  - Maintain constant body core temperature
  - Heat loss must match heat gain
- **Normal core temperature is 37°C**
  - Above 45°C
    - May destroy proteins and enzymes and lead to death
  - Below 34°C
    - May cause slowed metabolism and arrhythmias
- **Thermal gradient from body core to skin surface**
  - Ideal gradient is ~4°C
  - In extreme cold, may be 20°C

An Overview of Heat Balance

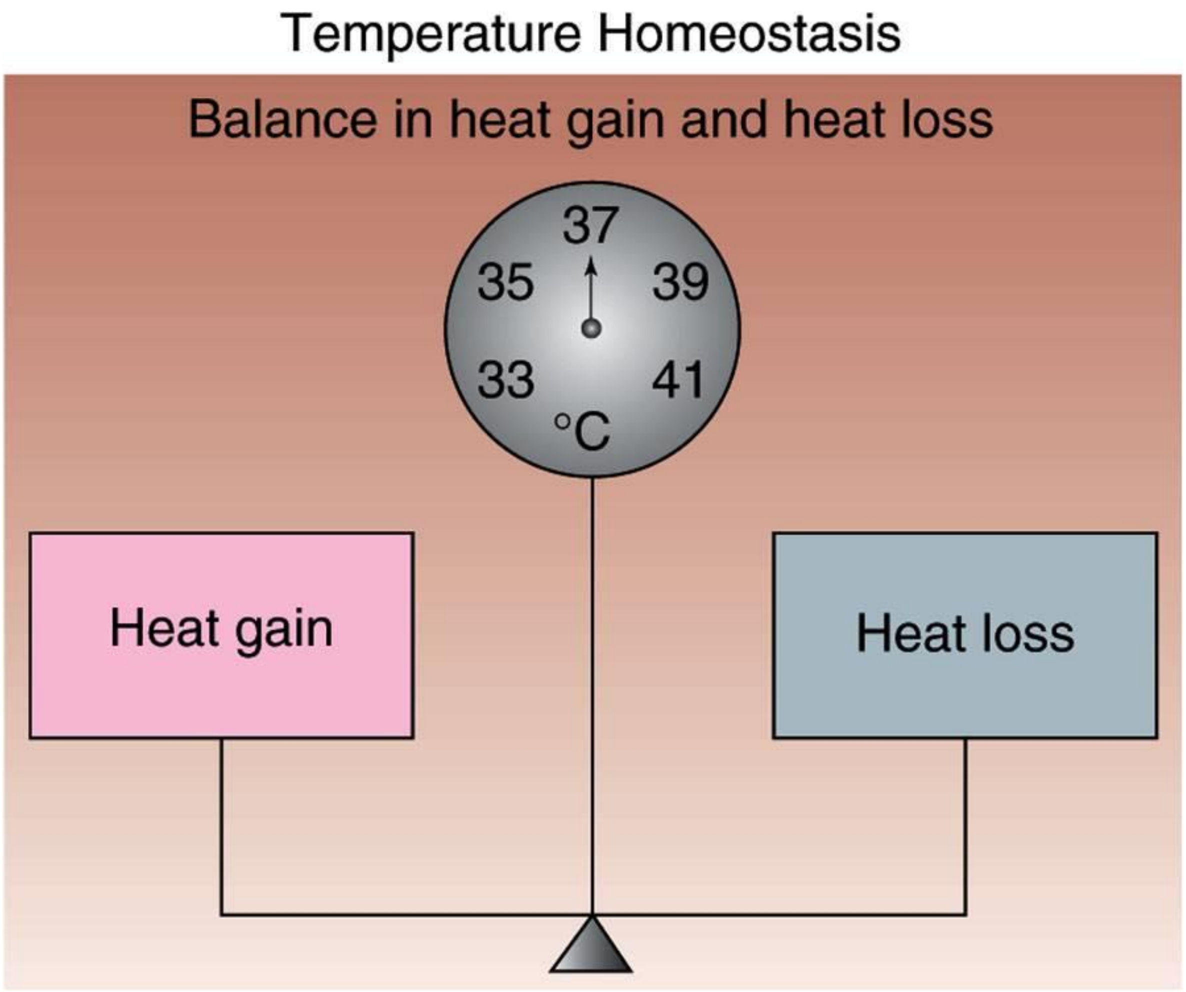
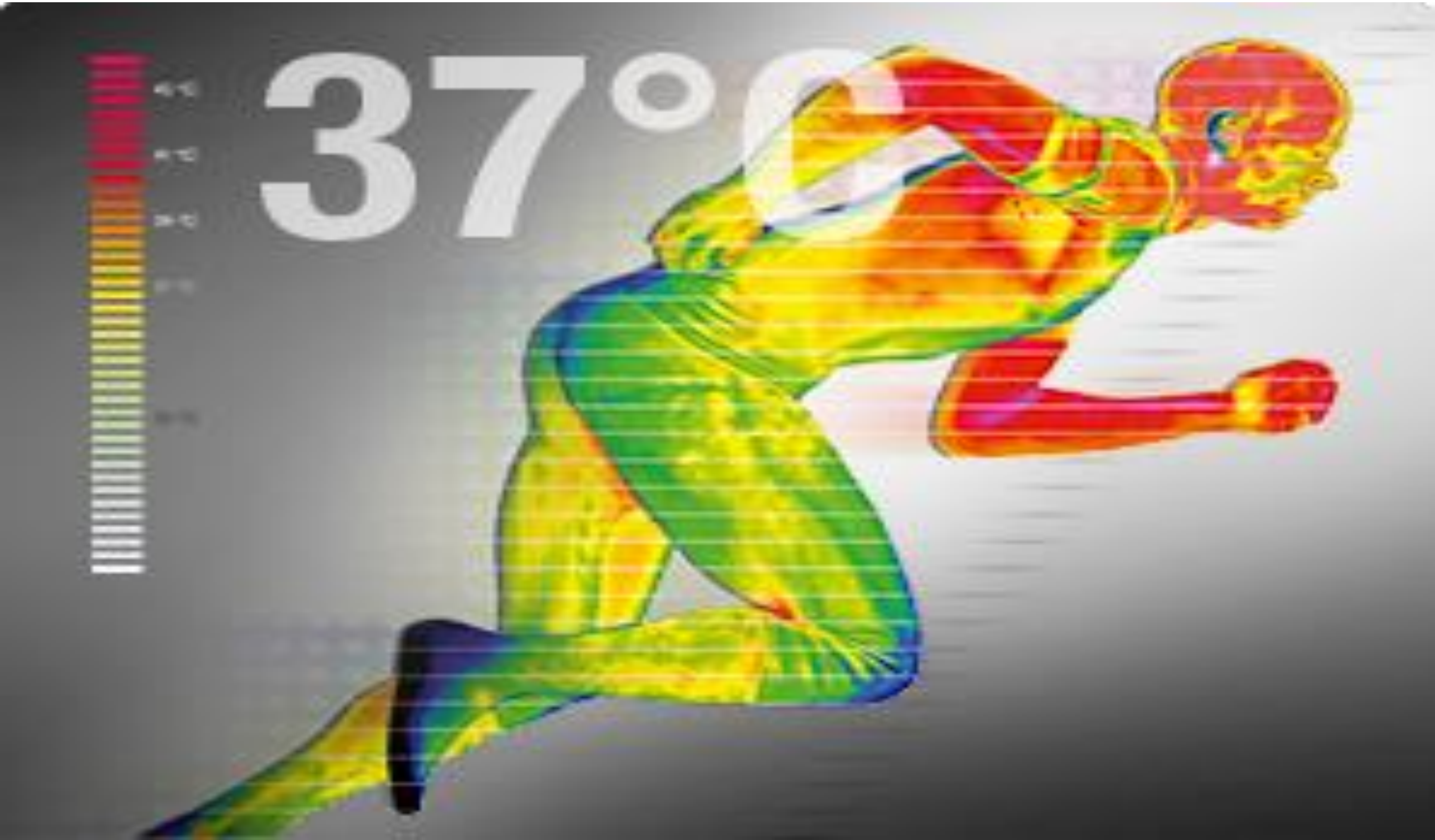


Figure 12.1

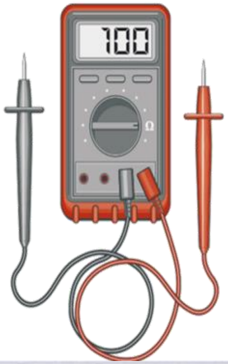
In Summary

- Homeotherms are animals that maintain a rather constant body core temperature. In order to maintain a constant core temperature, heat loss must match heat gain.
- Temperature varies a great deal within the body. In general, there is a thermal gradient from the deep bode temperature (core temperature) to the shell (skin) temperature.

Temperature Measurement During Exercise



Temperature Measurement During Exercise



- **Deep-body (core) temperature**
  - Measured at rectum, ear, or esophagus
    - Usually in laboratory
  - temperature sensor telemetry system
    - In athletes during practice sessions
- **Skin temperature**
  - Thermistors at various locations
  - Calculate mean skin temperature

$$T_{skin} = (T_{forehead} + T_{chest} + T_{forearm} + T_{thigh} + T_{calf} + T_{abdomen} + T_{back}) \div 7$$

In Summary

- Measurements of deep-body temperature can be accomplished via mercury thermometers, or devices known as thermocouples or thermistors. Common sites of measurement include the rectum, the ear (tympanic temperature), and the esophagus.
- Skin temperature can be measured by placing temperature sensors (thermistors) on the skin at various locations.

Heat Production

- **Voluntary**
  - Exercise
    - 70–80% energy expenditure appears as heat
- **Involuntary**
  - Shivering
    - Increases heat production by ~5x
  - Action of hormones
    - Thyroxine
    - Catecholamines

    Called **non-shivering thermogenesis**

Heat Production

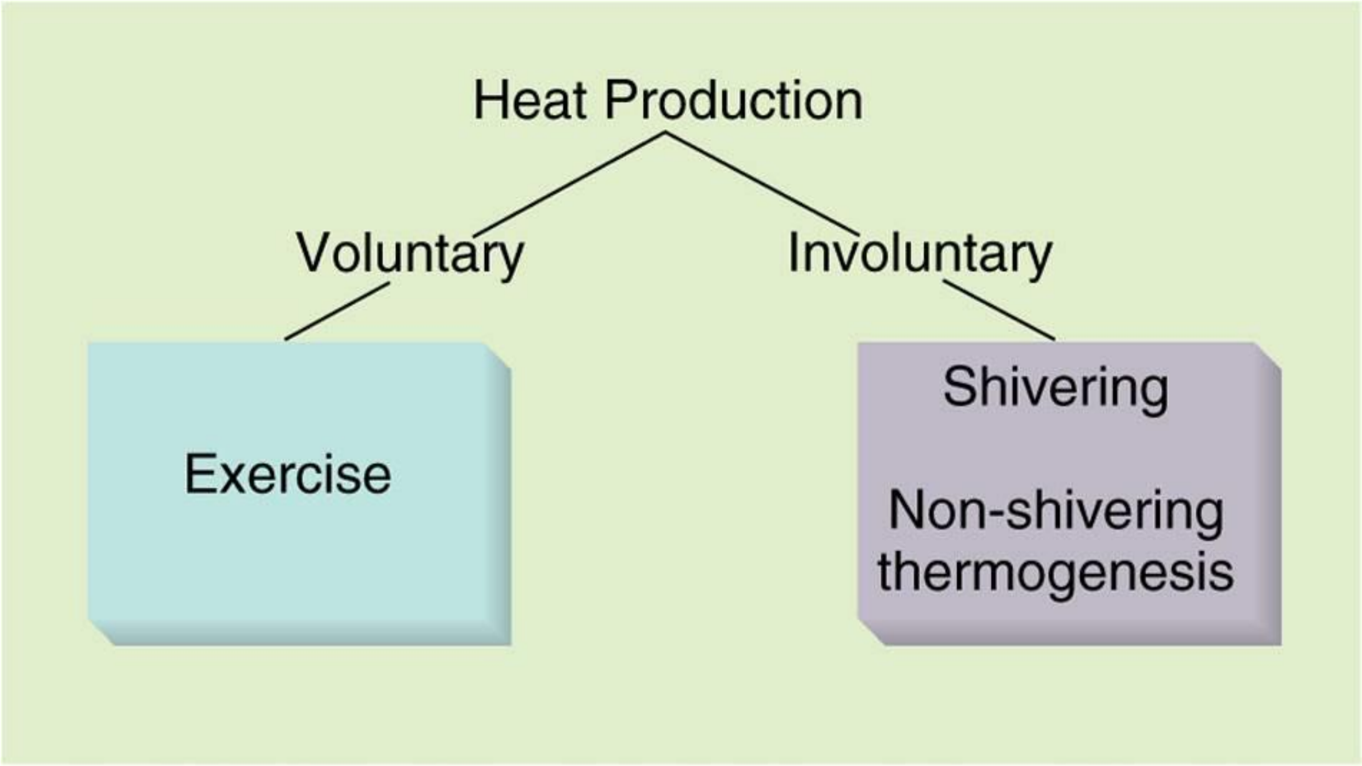
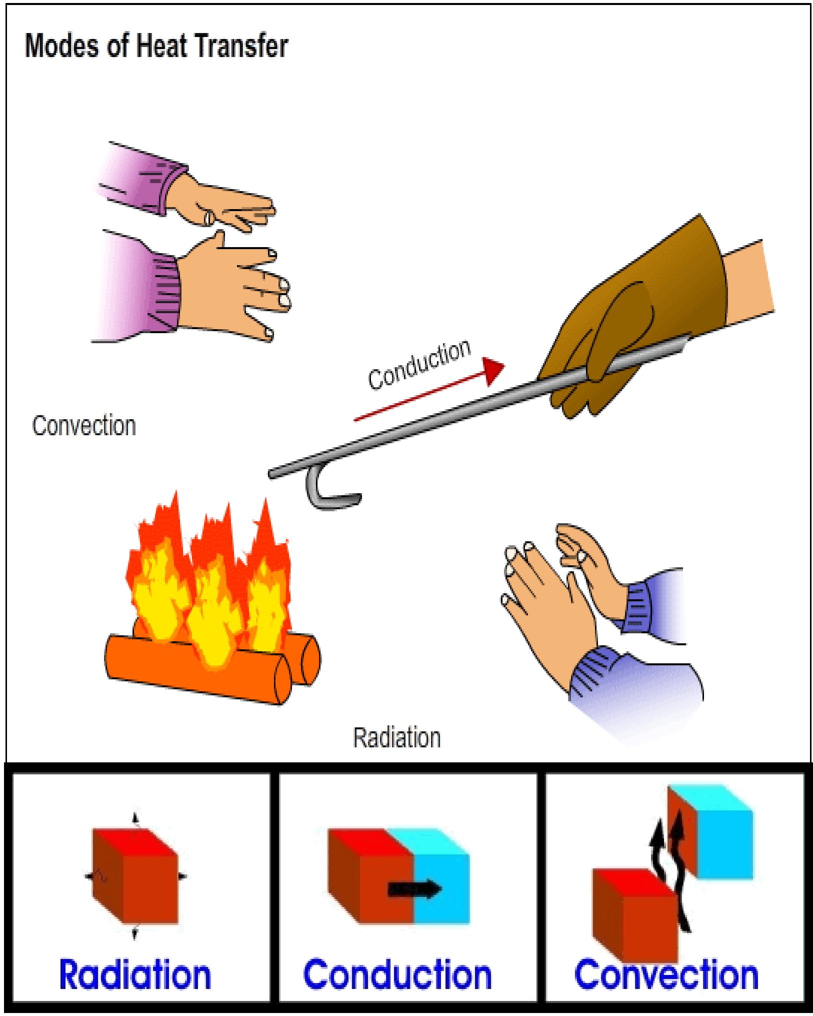
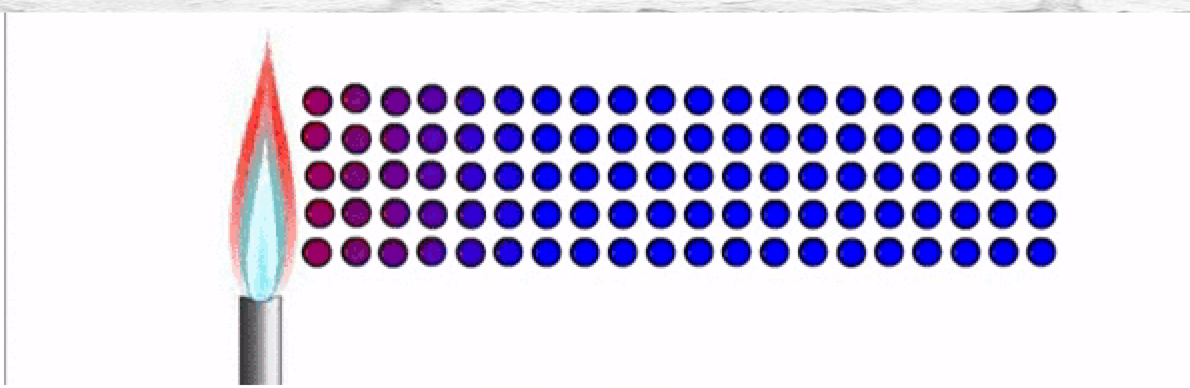


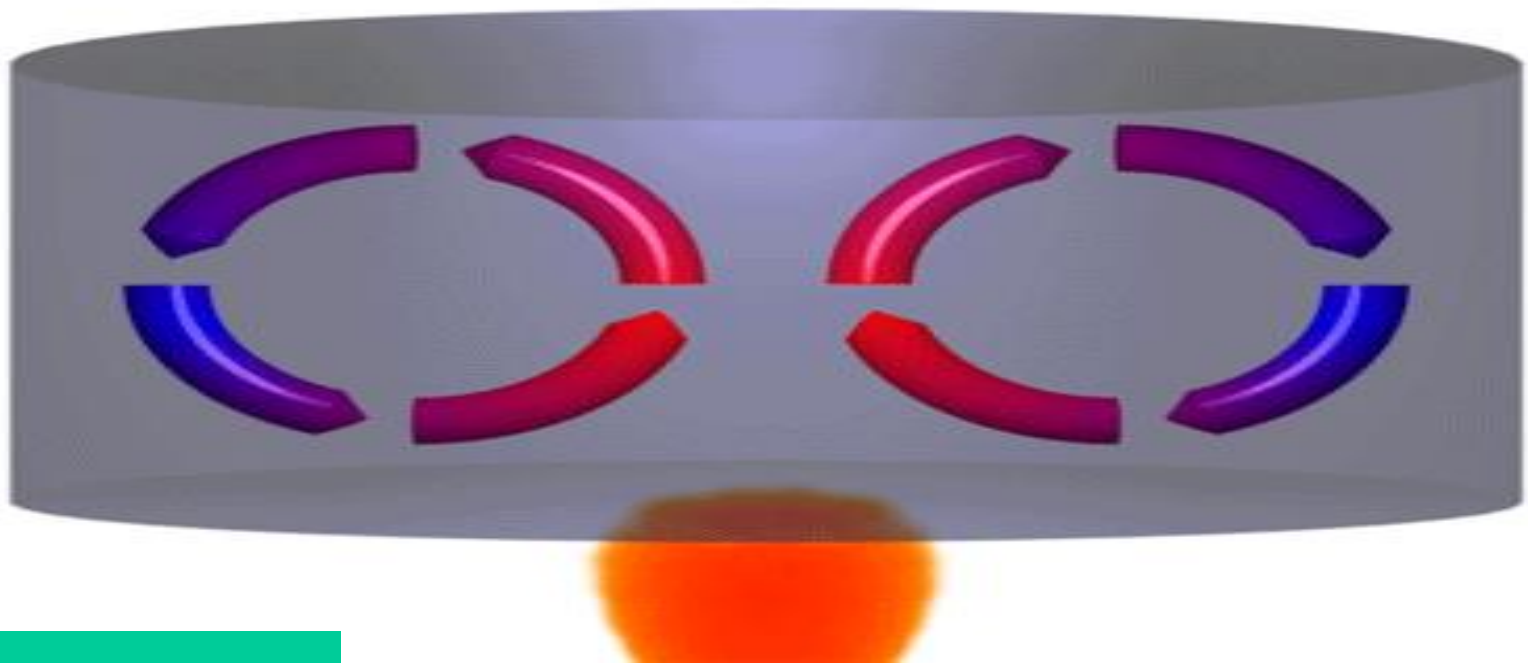
Figure 12.2

Heat Loss

- **Radiation**
  - Transfer of heat via infrared rays
  - 60% heat loss at rest
  - Can be a method of heat gain
- **Conduction**
  - Heat loss due to contact with another surface
- **Convection**
  - Heat transferred to air or water
  - Example: a fan pushing air past skin







28%


@SBNATION

Heat Loss

- **Evaporation**
  - Heat from skin converts water (sweat) to water vapor
    - Requires vapor pressure gradient between skin and air
  - Evaporation rate depends on:
    - Temperature and relative humidity
    - Convective currents around the body
    - Amount of skin surface exposed
  - Body loses 0.58 kcal heat/ml sweat evaporated
    - 1 L sweat results in heat loss of 580 kcal
  - 25% heat loss at rest
    - Most important means of heat loss during exercise

Temperature, Relative Humidity, and Vapor Pressure

TABLE 12.1 The Relationship Between Temperature and Relative Humidity (RH) on Vapor Pressure

50% RH Temperature °C	Vapor Pressure (mm Hg)
0	2.3
10	4.6
20	8.8
30	15.9
75% RH Temperature °C	**Vapor Pressure (mm Hg)**
0	3.4
10	6.9
20	13.2
30	23.9
100% RH Temperature °C	**Vapor Pressure (mm Hg)**
0	4.6
10	9.2
20	17.6
30	31.9

A Closer Look 12.1
Calculation of Heat Loss via Evaporation

We Know,

- **1,000 ml of sweat =580 kcal of heat loss**
- **Example:**
  - 20 min cycling at VO_2 = 2.0 L•min^{-1} (10 kcal•min^{-1})
    - 20% efficient = 80% energy lost as heat
  - Total energy expenditure (Time X energy expenditure)

    20 min x 10 kcal/min = 200 kcal
  - Total heat produced

    200 kcal x 0.80 = 160 kcal
  - Evaporation to prevent heat gain (Total heat produced /heat loss/liter)

    160 kcal ÷ 580 kcal/L = 0.276 L

Heat Exchange Mechanisms During Exercise

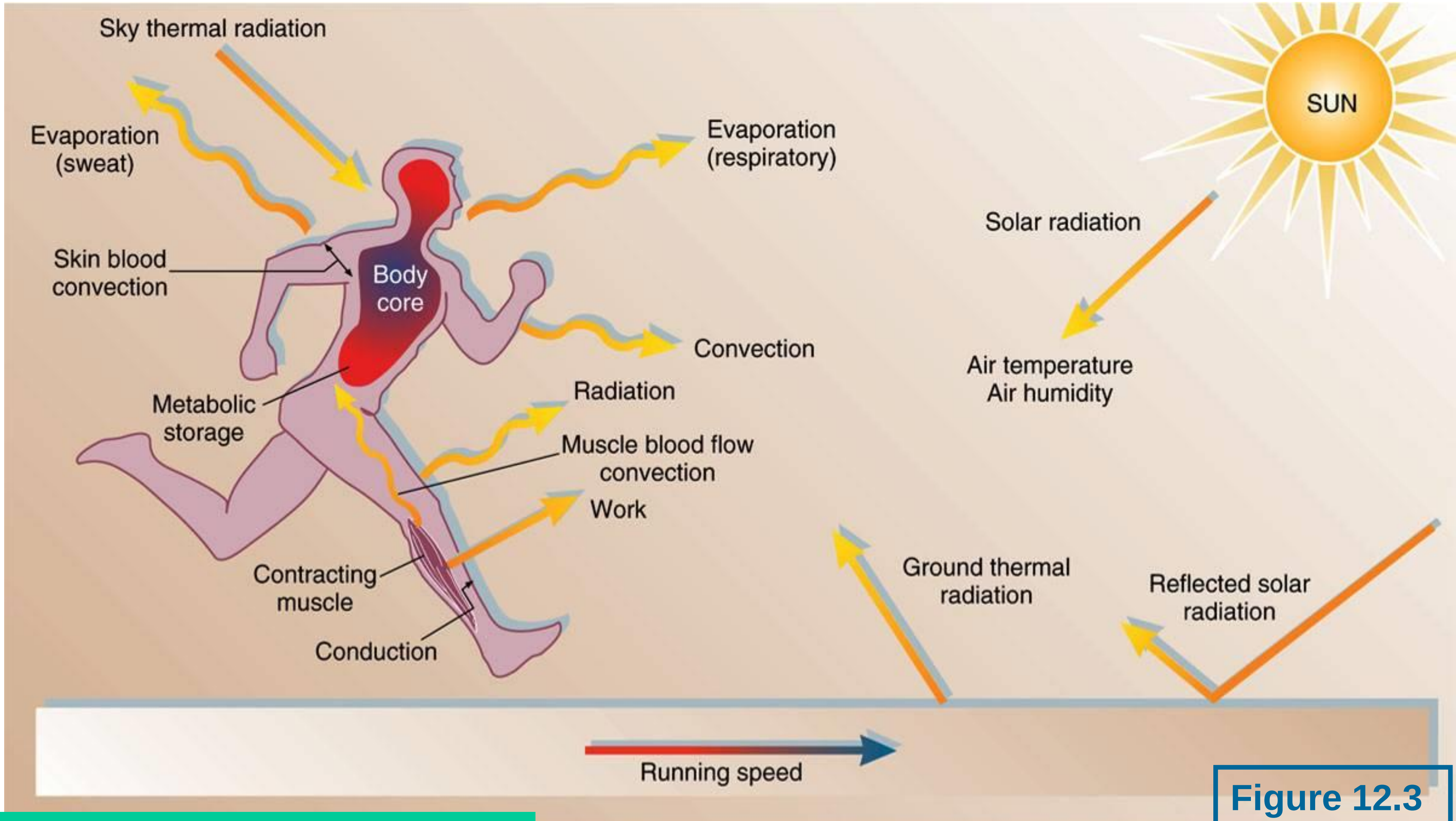


Figure 12.3

Heat Storage in the Body During Exercise

- **Heat produced that is not lost is stored in body tissues**
  - Will raise body temperature

Body heat gain during exercise = heat produced – heat loss

- **Amount of heat required to raise body temperature**
  - Specific heat of human body is 0.83 kcal/kg

Heat required to raise body temp 1°C = specific heat x body mass

Heat required to raise Your body temp 1°C

Calculation of Body Temperature Increase During Exercise

- **60-kg runner, 40 min at VO_2 = 3.0 L•min^{-1} (15 kcal•min^{-1})**
  - 20% efficient, can lose 60% of heat produced
  - Pre-exercise body temperature = 37°C
- **Total energy expenditure**
  40 min x 15 kcal/min = 600 kcal
- **Total heat produced**
  600 kcal x 0.80 = 480 kcal
- **Total heat stored**
  480 kcal x 0.40 = 192 kcal
- **Amount of heat storage to increase body temperature by 1°C**
  0.83 kcal/kg x 60 kg = 49.8 kcal
- **Increase in body temperature during exercise**
  192 kcal/49.8 kcal/°C = 3.86°C
- **Post-exercise body temperature**
  37°C + 3.86°C = 40.86°C

40%

In Summary

- Muscular exercise can result in large amounts of heat production. Since the body is at most 20% to 30% efficient, 70% to 80% of the energy expended during exercise is released as heat.
- Body heat can be lost by evaporation, convection, conduction, and radiation. During exercise in a cool environment, evaporation is the primary avenue for heat loss.

In Summary

- The rate of evaporation from the skin is dependent upon three factors: (1) temperature and relative humidity, (2) convective currents around the body, and (3) the amount of skin exposed to the environment.
- Body heat storage is the difference between heat production and heat loss.
- The amount of heat required to elevate body temperature by 1°C is termed the specific heat of the body.

The Body's Thermostat—Hypothalamus

- **Anterior hypothalamus**
  - Responds to increased core temperature
  - Commencement of sweating
    - Increased evaporative heat loss
  - Increased skin blood flow
    - Allows increased heat loss
- **Posterior hypothalamus**
  - Responds to decreased core temperature
  - Shivering and increased norepinephrine release
    - Increased heat production
  - Decreased skin blood flow
    - Decreased heat loss

Physiological Responses to "Heat Load"

Physiological response to a "Heat Load"

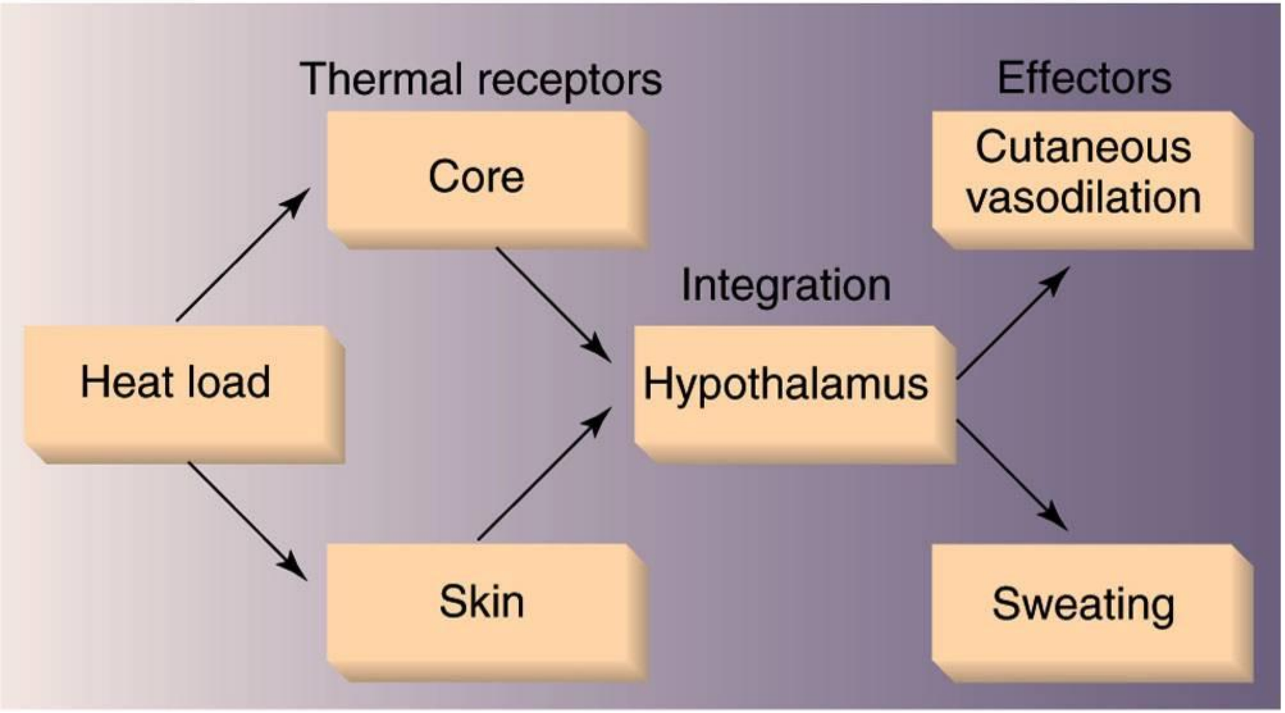


Figure 12.4

Physiological Responses to Cold Stress

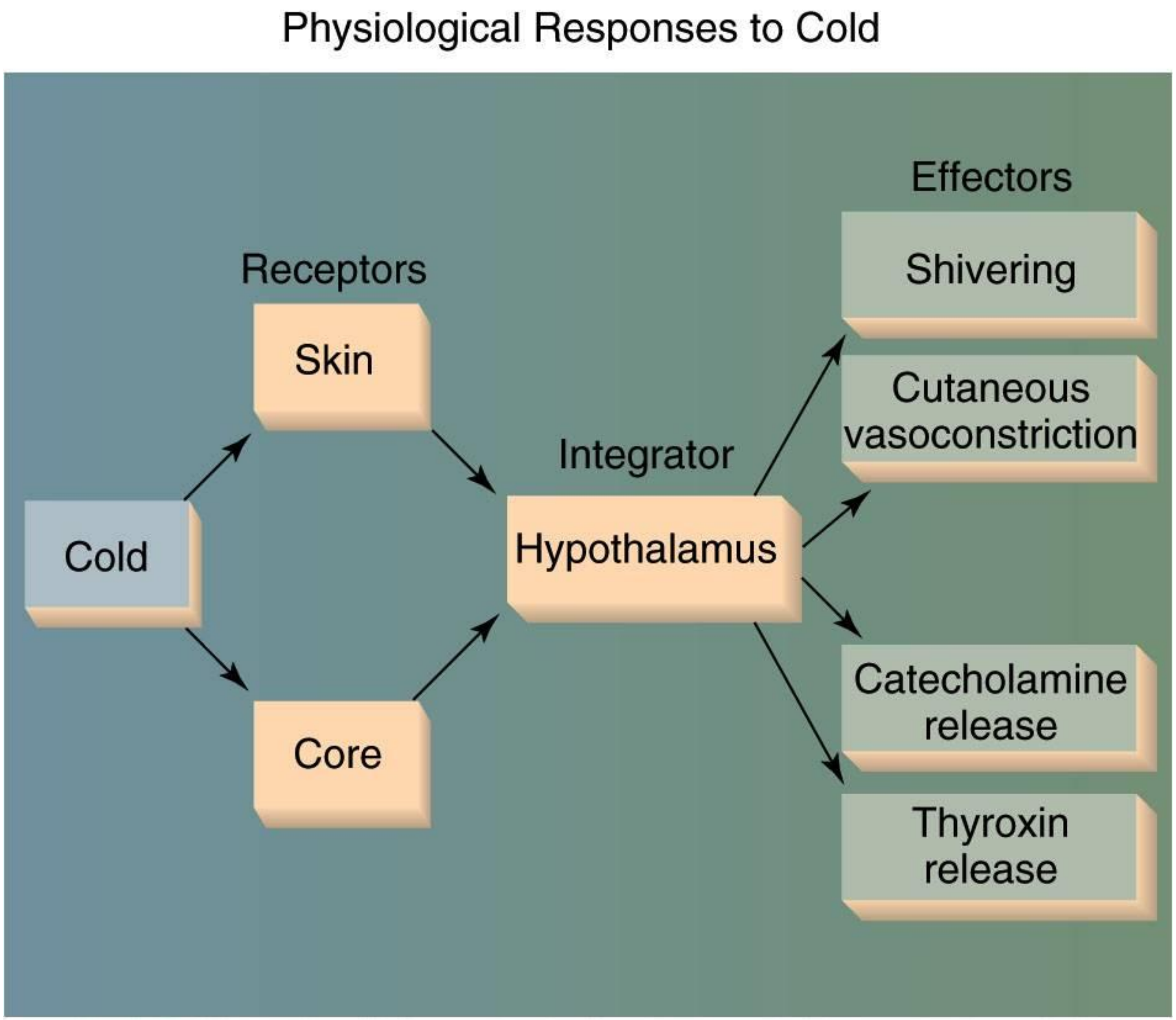


Figure 12.5

Shift in Hypothalamic Set Point Due to Fever

- **Fever**
  - Increased body temperature above normal
  - Due to pyrogens
    - Proteins or toxins from bacteria
  - Change in set point of hypothalamus

In Summary

- The body's thermostat is located in the hypothalamus.
- The anterior hypothalamus is responsible for reacting to increases in core temperature, while the posterior hypothalamus governs the body's responses to a decrease in temperature.
- An increase in core temperature results in the anterior hypothalamus initiating a series of physiological actions aimed at increasing heat loss. These actions include: (1) the commencement of sweating and (2) an increase in skin blood flow.

In Summary

- Cold exposure results in the posterior hypothalamus promoting physiological changes that increase body heat production (shivering) and reduce heat loss (cutaneous vasoconstriction).

Thermal Events During Exercise

- **As exercise intensity increases:**
  - Heat production increases
  - Linear increase in body temperature
    - Core temperature proportional to active muscle mass
  - Higher net heat loss
    - Lower convective and radiant heat loss
    - Higher evaporative heat loss
- **As ambient temperature increases:**
  - Heat production remains constant
  - Lower convective and radiant heat loss
  - Higher evaporative heat loss

Changes in Metabolic Energy Production and Heat Loss During Exercise

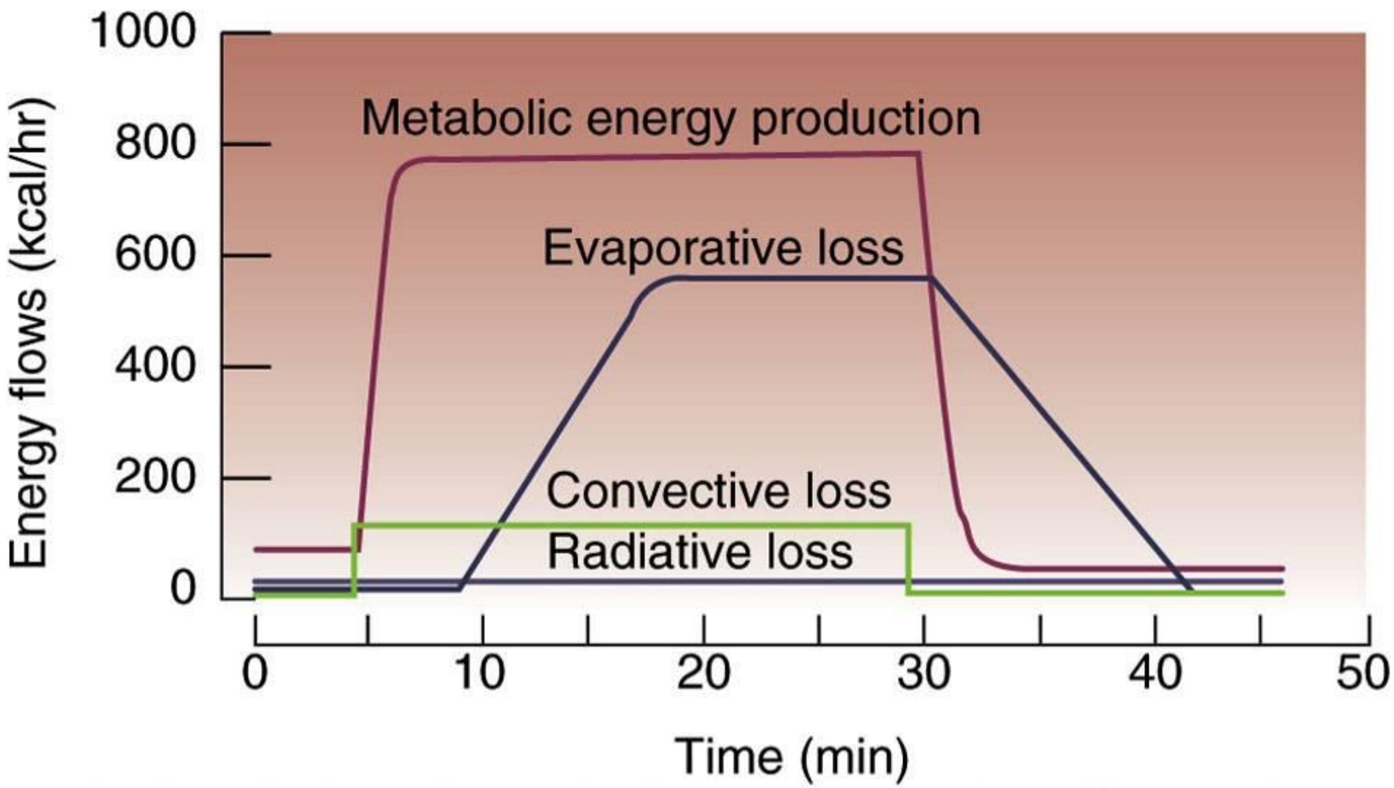


Figure 12.6

Body Temperature During Arm and Leg Exercise

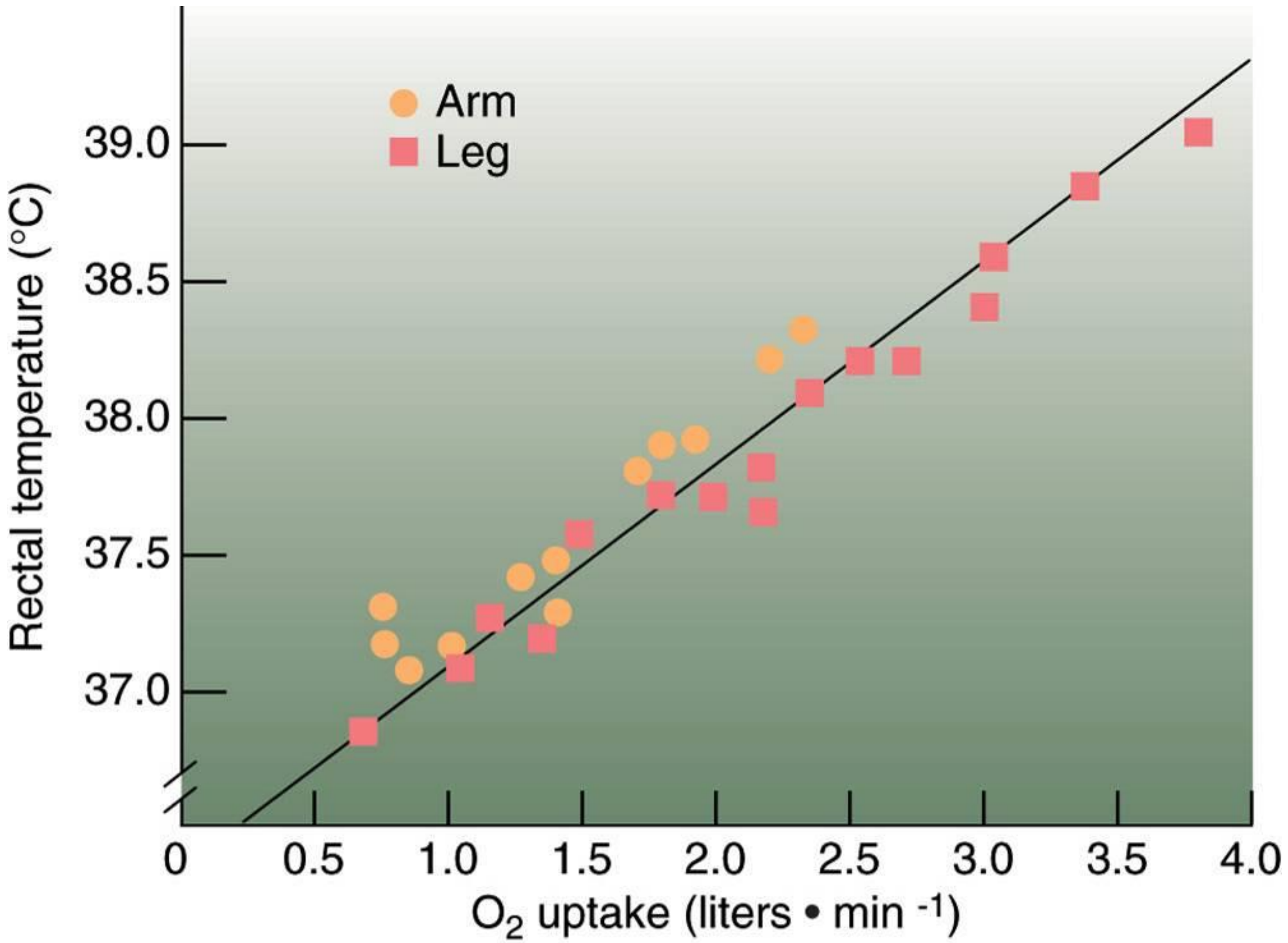


Figure 12.7

Thermal Events During Exercise

- **Increase in body temperature is directly related to exercise intensity**
  - Body heat load increases with intensity
- **Mechanisms of heat loss during exercise**
  - Evaporation
    - Most important means of heat loss
  - Convection
    - Small contribution
  - Radiation
    - Small role in total heat loss

Heat Exchange At Rest and During Exercise

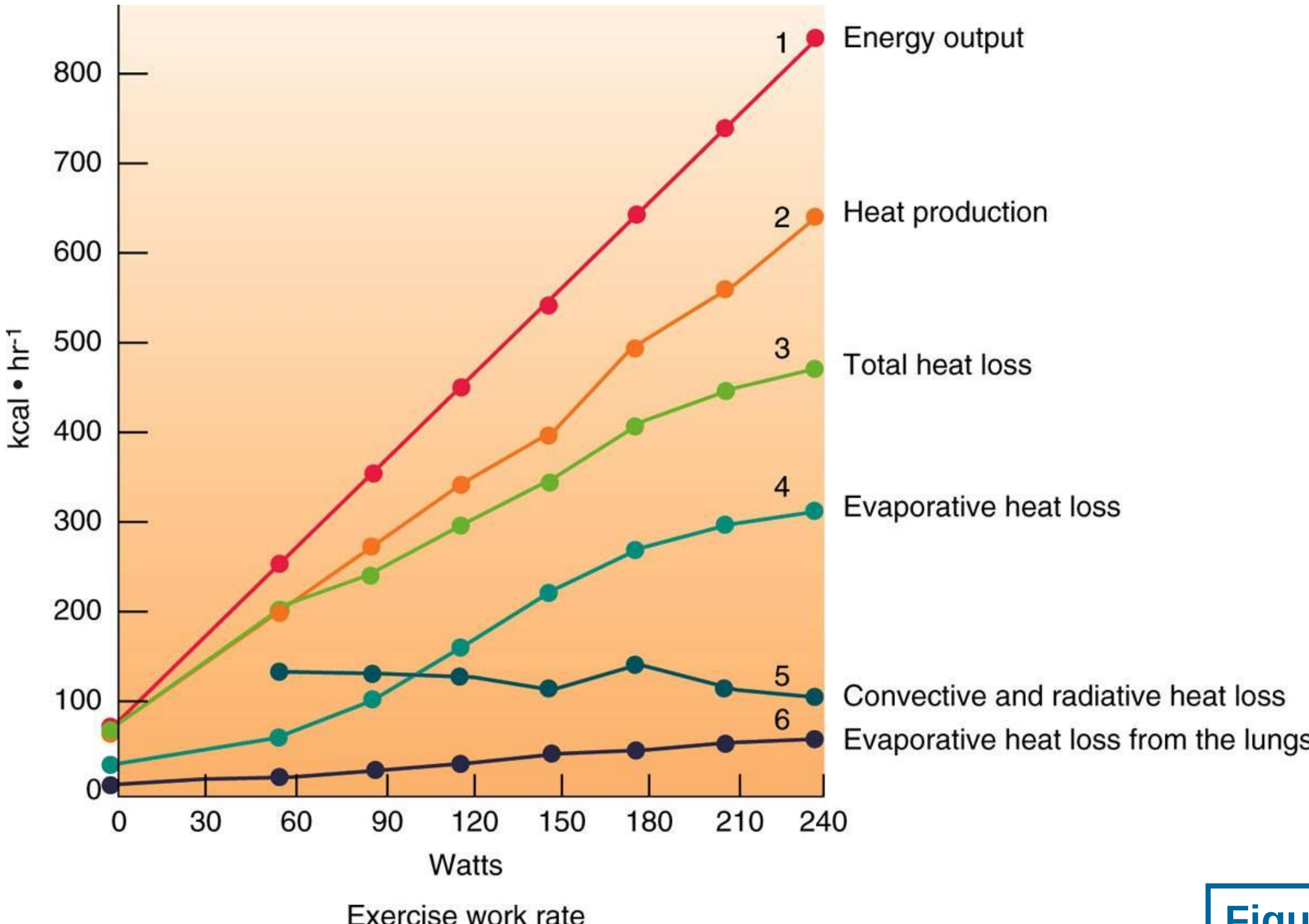


Figure 12.9

In Summary

- During constant intensity exercise, the increase in body temperature is directly related to the exercise intensity.
- Body heat production increases in proportion to exercise intensity.

Heat Index

- **Measure of body's perception of how hot it feels**
  - Relative humidity added to air temperature
- **Example:**
  - Air temperature = 80°F, relative humidity = 80%
  - Heat index = 89°F
- **High relative humidity reduces evaporative heat loss**
  - Lowers heat loss
  - Increases body temperature

NWS Heat Index

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution · Extreme Caution · Danger · Extreme Danger

Exercise in the Heat

- **Inability to lose heat**
  - Higher core temperature
  - Risk of hyperthermia and heat injury
- **Higher sweat rate**
  - May be as high as 4–5 L/hour
  - Risk of dehydration

Core Temperature and Sweat Rate During Exercise in a Hot/Humid Environment

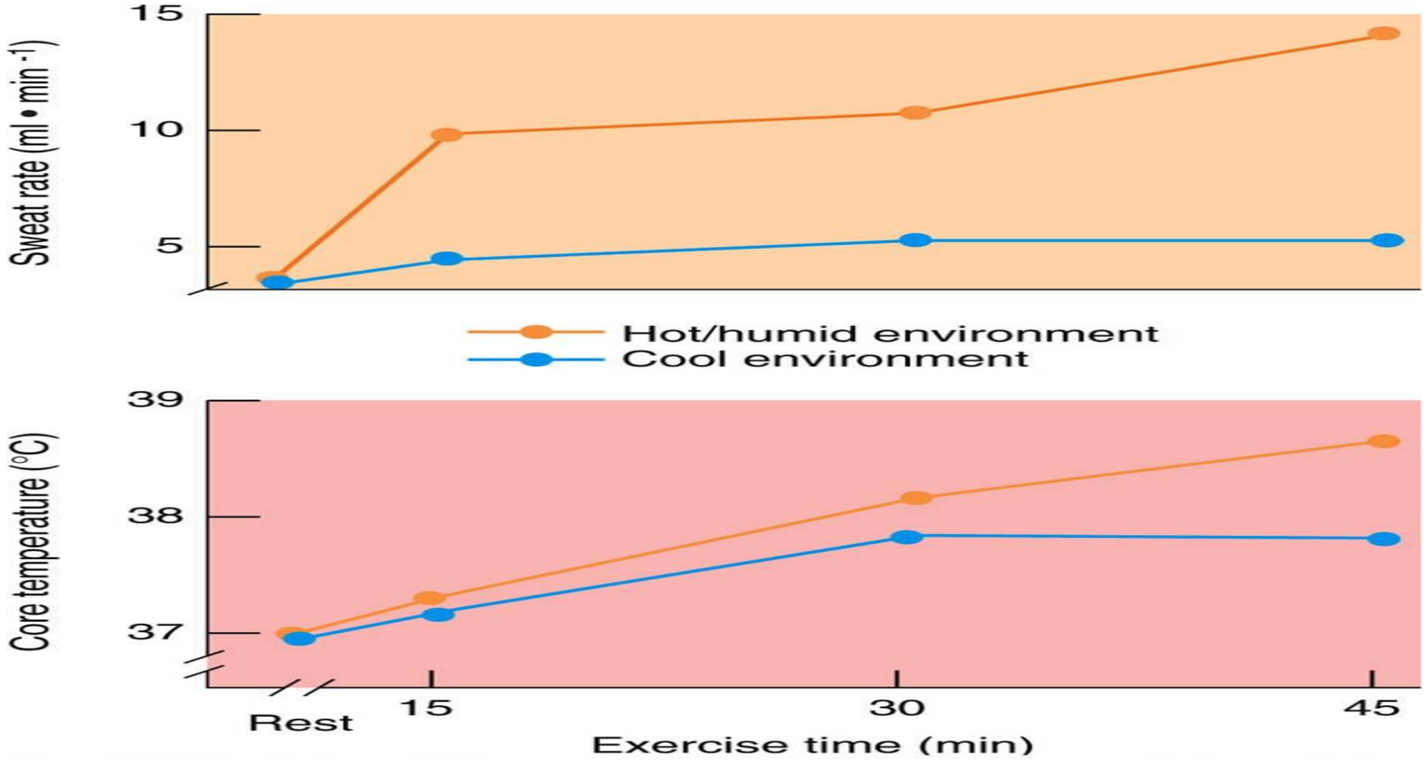


Figure 12.11

Clinical Applications 12.1

Exercise-Related Heat Injuries Can Be Prevented

- **Guidelines**
  - Exercise during the coolest part of the day
  - Minimize exercise intensity and duration on hot/humid days
  - Expose a maximal surface area of skin for evaporation
  - Provide frequent rests/cool-down breaks with equipment removal
  - Avoid dehydration with frequent water breaks
  - Rest/cool-down breaks should be in the shade and offer circulating, cool air

Prevention of Dehydration During Exercise

- **Dehydration of 1–2% body weight can impair performance**
- **Guidelines**
  - Hydrate prior to performance
    - 400–800 ml fluid within three hours prior to exercise
  - Consume 150–300 ml fluid every 15–20 min
    - Volume adjusted based on environmental conditions
  - Ensure adequate rehydration
    - Consume equivalent of 150% weight loss
    - 1 kg body weight = 1.5 L fluid replacement
  - Monitor urine color
- **Sports drinks are superior to water for rehydration**

Exercise Performance in a Hot Environment

- **Can result in muscle fatigue and impaired performance**
  - Reduced mental drive for motor performance
  - Reduced muscle blood flow
  - Accelerated glycogen metabolism
  - Increased lactic acid production
  - Increased free radical production

Research Focus 12.1

Exercise in the Heat Accelerates Muscle Fatigue

- **Rapid onset of muscle fatigue in hot/humid environments**
- **Heat-related muscle fatigue due to:**
  - – High brain temperature reduces neuromuscular drive
    - Reduction in motor unit recruitment
  - – Accelerated muscle glycogen metabolism and hypoglycemia
    - Controversial
  - – Increased free radical production
    - Damage to muscle contractile protein

Gender and Age Differences in Thermoregulation

- **Women less heat tolerant than men**
  - Lower sweat rates
  - Higher percent body fat
- **Age itself does not limit ability to thermoregulate**
  - Decreased thermotolerance with age due to:
    - Deconditioning with age
    - Lack of heat acclimatization

Heat Acclimatization

- **Requires exercise in hot environment**
- **Adaptations occur within 7–14 days**
  - Increased plasma volume
  - Earlier onset of sweating
  - Higher sweat rate
  - Reduced sodium chloride loss in sweat
  - Reduced skin blood flow
  - Increased cellular heat shock proteins
- **Acclimatization lost within a few days of inactivity**

Can Sweat Clothing Promote Heat Acclimatization?

- **Training in cool climates using sweat clothing**
  - Alternative to traveling to warmer climate to acclimatize
  - Raises body temperature
- **Does it work?**
  - Yes, but not as effective as training in hot/humid environment
- **Increases sweat rate and body water loss**
  - Not effective for fat loss
- **Risk of hyperthermia and heat injury**

Research Focus 12.3

Heat Acclimatization and Heat Shock Proteins

- **Heat acclimatization reduces the risk of heat injury**
  - In response to exposure of heat stress
- **Related to synthesis of heat shock proteins**
  - Protect cells from thermal injury
  - Stabilizing and refolding damaged proteins

Primary Adaptations of Heat Acclimatization

TABLE 12.2 A Summary of the Primary Adaptations That Occur as a Result of Heat Acclimatization

1. Increased plasma volume
2. Earlier onset of sweating
3. Higher sweat rate
4. Reduced sodium chloride loss in sweat
5. Reduced skin blood flow
6. Increased heat shock proteins in tissues

In Summary

- During prolonged exercise in a moderate environment, core temperature will increase gradually above the normal resting value and will reach a plateau at approximately thirty to forty-five minutes.
- During exercise in a hot/humid environment, core temperature does not reach a plateau, but will continue to rise. Long-term exercise in this type of environment increases the risk of heat injury.
- Heat acclimatization results in: (1) an increase in plasma volume, (2) an earlier onset of sweating, (3) a higher sweat rate, (4) a reduction in the amount of electrolytes lost in sweat, (5) a reduction in skin blood flow, and (6) increased levels of heat shock protein in tissues.

Exercise in a Cold Environment

- **Enhanced heat loss**
  - Reduces chance of heat injury
  - May result in hypothermia
    - Loss of judgment and risk of further cold injury
- **Cold acclimatization**
  - Results in lower skin temperature at which shivering begins
    - Increased nonshivering thermogenesis
  - Maintain higher hand and foot temperature
    - Improved peripheral blood flow
  - Improved ability to sleep in the cold
    - Due to reduced shivering
  - Adaptations begin in one week

In Summary

- Exercise in a cold environment enhances an athlete’s ability to lose heat and therefore greatly reduces the chance of heat injury.
- Cold acclimatization results in three physiological adaptations: (1) improved ability to sleep in cold environments, (2) increased nonshivering thermogenesis, and (3) a higher intermittent blood flow to the hands and feet. The overall goal of these adaptations is to increase heat production and maintain core temperature, which will make the individual more comfortable during cold exposure.

Study Questions

1. **Define the following terms: (1) *homeotherm*, (2) *hyperthermia*, and (3) *hypothermia*.**
2. **Why does a significant increase in core temperature represent a threat to life?**
3. **Explain the comment that the term *body temperature* is a misnomer.**
4. **How is body temperature measured during exercise?**
5. **Briefly discuss the role of the hypothalamus in temperature regulation. How do the anterior hypothalamus and posterior hypothalamus differ in function?**

Study Questions

6. List and define the four mechanisms of heat loss. Which of these avenues plays the most important part during exercise in a hot/dry environment?
7. Discuss the two general categories of heat production in people.
8. What hormones are involved in biochemical heat production?
9. Briefly outline the thermal events that occur during prolonged exercise in a moderate environment. Include in your discussion information about changes in core temperature, skin blood flow, sweating, and skin temperature.

Study Questions

10. Calculate the amount of evaporation that must occur to remove 400 kcal of heat from the body.
11. How much heat would be removed from the skin if 520 ml of sweat evaporated during a thirty-minute period?
12. List and discuss the physiological adaptations that occur during heat acclimatization.
13. How might exercise in a cold environment affect dexterity in such skills as throwing and catching?
14. Discuss the physiological changes that occur in response to chronic exposure to cold.