Eugene

Energy in Sport

2024-02-19

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0.1 Energy & Training

Homeostasis

- optimum temperature
- optimum pH
- optimal glucose levels
- etc

Adaptations

- overload principle
- specificity
- reversibility
- individuality

0.2 Calorimetry

- Direct: measure heat produced during exercise - Human Calorimetry Chamber
- Indirect: measure O_2 consumption (VO_2) typically about 0.25mL/kg/s of VO_2 during exercise 0.05mL/kg/s of VO_2 during rest

0.3

- Maximum VO_2 measured by exercising to exhaustion get up to 1mL/kg/s
- corresponds to about 250 Watts of power
- training will increase your VO_2 max
- cardiovascular adaptations giving better O_2 delivery
- muscle mitocondrial O_2 utilisation
- athletes using large muscle masses for extended periods tend to have highest VO_2 max

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0.4 Respiratory Exchange Ratio (RER)

as well as measuring O_2 levels we also monitor CO_2 gives us the RER

$$RER = \frac{V_{CO_2}}{V_{O_2}}$$

This gives information on type of food being used

- for fats, RER = 0.7
- for glucose, RER = 1.0

Fats, e.g. palmitate, $C_{16}H_{32}O_2$ + 23 O_2 -> 16 CO_2 + 16 H_2O

$$\frac{16}{23} = 0.70$$

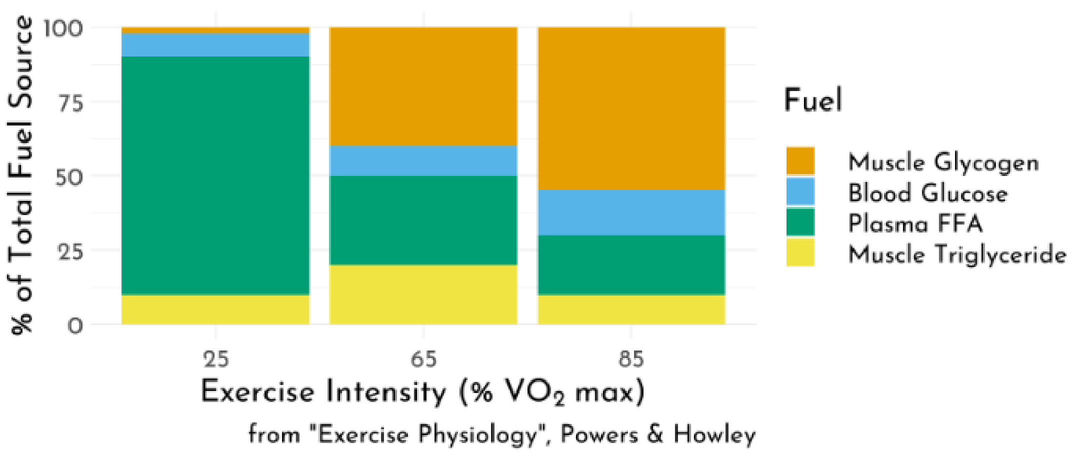
Glucose, $C_6H_{12}O_6$ + 6 O_2 -> 6 CO_2 + 6 H_2O

$$\frac{6}{6} = 1.0$$

0.5 Fuel depends on Type of Exercise

- for long distance, endurance, RER lets us deduce that mostly fats are burned
- for high-powered activities like sprinting, mostly carbohydrates

0.6 CHO's needed at higher intensities



0.7 Fuel used During a Marathon

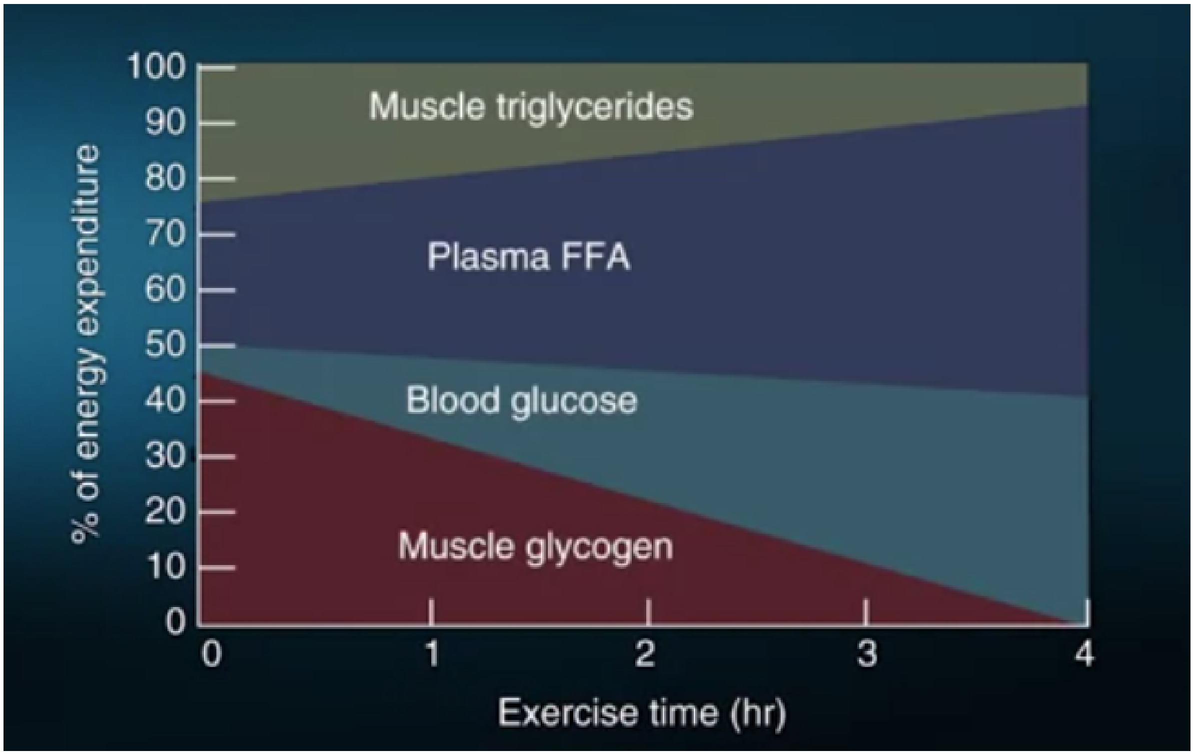
- muscle triglycerides: provide ~ 30% of energy initially but fades to ~10% gradually over four hours
- plasma FFA: provide ~ 20% initially but this grows to 50% over four hours
- blood glucose: provides 10% initially, this grows to 40% after four hours

0.8

- muscle glycogen: provides ~ 40% initially but fades out over about 3 hours
- decrease in CHO use leads to a decrease inperformance and to the onset of fatigue

See this video for a discussion of energy use in sled dogs.

0.9 Fuel used During a Marathon



0.10 Crossover Concept

As exercise intensity increases

- progressive **decrease** in **fats** as fuel source
- progressive **increase** in **CHO** as fuel source

Training adaptation - push this crossover point to higher intensities

Leads to sparing of precious CHO stores

Pushes back onset of fatigue

0.11 ATP & Muscle Work

Only ATP can be used to directly cause muscle contraction

- Breakdown of ATP allows crossbridge formation between actin and myosin (enzyme ATPase)
- Amount of ATP in muscle is extremely low
- During exercise as ATP utilisation goes up, need to replace it

$$ATP_{prod} = ATP_{util}$$

ATP producing pathways turns on by the *energy charge* in the cell

$$Energy\ Charge = \frac{[ATP] + \frac{1}{2}[ADP]}{[ATP] + [ADP] + [AMP]}$$

At rest, the *energy charge* in muscle is about 0.85 As *energy charge* decreases, ATP producing pathways are turned on while ATP utilising pathways are turned off

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0.12 Mitochondria

Oxidative production of ATP occurs in mitochondria.

This is vast majority of ATP production.

- Aerobic activity
- For exercise lasting minutes or longer
- shorter bouts of exercise use anaerobic pathways for ATP production

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0.13 Anaerobic Sources of Energy

Activities lasting seconds need energy immediately Access stores of ATP in the cell

$$ATP + H_2O \rightarrow ADP + P_i \qquad ATP_{ase}$$

$$CP + ADP \rightarrow ATP + C \qquad creatine\ kinase$$

No O_2 in either process

About 3 or 4 times more CP than ATP in cell.

0.14 Carbohydrates

Carbohydrate can be broken down anaerobically

$$C_6H_{12}O_6 \rightarrow 2ATP + 2\ lactate$$

Or aerobically

$$C_6H_{12}O_6 + 6O_2 \rightarrow 30ATP + 6CO_2 + 6H_2O$$

(note, for the same glucose molecule we get 15 times more ATP when broken aerobically) Limited amount of carbohydrate in the body, aerobic metabolism helps preserves carbohydrate stores.

0.15

Fats can also be broken down aerobically

$$Palmitate + 23O_2 \rightarrow 108ATP + 16CO_2$$

0.16 Carbohydrate Storage

Carbohydrates stored as *Glycogen*

Glycogen = strings of glucose attached to each other

When glucose needed, peeled off from glycogen

0.16.1 Muscle Glycogen

- typically 400g = 1600kCal
- this is ~90mM/kg of muscle
- can be depleted in minutes
- carbohydrate loading: supercharges muscles with up to 250mM/kg of muscle
- useful for exercises of > 90 minutes

0.16.2 Liver Glycogen

- typically 100g = 400kCal
- needed to maintain blood glucose levels

0.16.3 Blood

- typically 3g = 12kCal (i.e. not very much)

Total of 2000kCal can be depleted during endurance exercise This isn't very much (gets depleted).

0.17 Compare to Fat Storage

Adipose Tissue

- typically 12kg = 108,000kCal
- fifty times more energy than carbohydrates
- key aerobic training adaptation is being able to use fat stores
- this preserves carbohydrate stores

0.18 To What Extent do we use Carbohydrates?

- **Intensity and duration of exercise**
- at low intensities use fats
- at high intensities use carbohydrates
- at high intensities use mostly type II muscle fibres
- Type of activity
- **Crossover Concept**
- Nutritional status

0.19 Different Muscle Fibres

0.20 Getting CHO from Glycogen

- glucose molecule stripped off by glycogen phosphorylase.
- prompted by release of epinephrine or by Ca++ in muscle.
- at high exercise intensities, muscle glycogen can drop from 90mM/kg to less 20mM/kg in minutes.
  - using mostly type II muscle fibres

0.21 Liver Glycogen

- provides glucose for blood glucose levels
- necessary to avoid exercise induced hypoglycemia
- muscle uptake from blood is up to 50mM/min
- normal liver glucose levels are about 4mM/L (about 5L of blood in human body)

TABLE 8-1

Characteristics of Skeletal Muscle Fibers

	TYPE OF FIBER		
CHARACTERISTIC	Slow-Oxidative (Type I)	Fast-Oxidative (Type IIa)	Fast-Glycolytic (Type IIx)
Myosin–ATPase Activity	Low	High	High
Speed of Contraction	Slow	Fast	Fast
Resistance to Fatigue	High	Intermediate	Low
Oxidative Phosphorylation Capacity	High	High	Low
Enzymes for Anaerobic Glycolysis	Low	Intermediate	High
Mitochondria	Many	Many	Few
Capillaries	Many	Many	Few
Myoglobin Content	High	High	Low
Color of Fiber	Red	Red	White
Glycogen Content	Low	Intermediate	High

Figure 1: Muscle Fibres

0.22 Carbohydrate Loading

- increase CHO content in muscles prior to exercise
- can get up to 250 mM/kg of muscle
- (compare to 90 mM/kg normally)
- increase CHO intake in week prior to exercise
- roughly double it to ~0.6kg/day
- rest for day or so before exercise

0.23 Carbohydrate Feeding

- consumption of very dilute CHO drink during exercise
- athletes at 70% VO_2 max can exercise for ~4 hours rather than 3 hours before fatigue
- gives addition source of CHO thus sparing liver glycogen

0.24 Training Adaptations

- sedentary individuals can double their cell mitochondrial content through training
- takes several weeks
- means using more CHO aerobically rather than anaerobically
- as we've seen, this is more more efficient
- spares muscle CHO content
- also observe a lower ***RER*** for individuals after training
- lower RER means greater fat usage
- this happens at all VO_2 % levels

0.25 Carbohydrate Summary

- exercise intensity and fibre recruitment determine CHO utilisation
- we have limited CHO stores (mostly in muscle)
- liver glycogenolysis maintains blood glucose
- carbohydrate loading increase muscle glucose levels before exercise
- carbohydrate feeding maintains blood glucose during exercise

0.26 Fat Metabolism During Exercise

- free fatty acids are immediate source of energy
- fats must be converted to FFA's before being used
- FFA's are hydrocarbon chains that can readily be oxidised in mitochondria
- FFA's stored in the form of triglycerides
- triglycerides stored in adipose tissue (mostly) or skeletal muscle

0.27 Fat Usage During Exercise

- during prolonged exercise, more energy harvested from adipose fats
  - decrease in use of CHO's and muscular triglycerides
- in contrast, as exercise intensity increases, less energy from adipose stores
  - crossover concept
- training adaptations for endurance:
  - greater ability to rely on fat energy stores at any exercise intensity
  - greater carbohydrate sparing

0.28 Fats Summary

- FFA for direct ATP production
- triglycerides are storage form
- vast bulk of fat storage in adipose tissue ($>$ 100,000 Cal)
- some fat storage in muscles (~ 3000Cal)
- fats are preferred fuel at low exercise intensities
- training adaptation is better use of fats

0.29 Protein Metabolism

- proteins made from amino acids
- to be used as fuel (contribute ~10%), proteins must be broken down to constituent AA's
- some AA's used directly as fuel, others converted to CHO and fat
- Nitrogen balance - protein intake
  - positive for growing children and intense weight training
- typical adult diet ~ 60g protein / day
  - double this for endurance training
  - triple it for strength training

0.30 Muscle Protein Synthesis

- decreases during exercise
  - energy charge drops - inhibits synthesis
- but significantly increases post exercise
  - increase protein intake 1 hour post exercise

1 Body Adaptations to Exercise

- Muscular
- Respiratory
- Cardiovascular
- Endocrine
- Immune

1.1 Muscle

- 3 types of muscle
  - cardiac
  - skeletal
  - smooth (e.g. around blood vessels)

1.2 Skeletal Muscle

- contractions
  - isometric
  - concentric (most common type)
  - eccentric (main source of muscle soreness after exercise)

1.3 Different Muscle Fibres

- Type IIx
  - fast
  - few mitochondria
  - anaerobic
  - sprinting / weight lifting
  - 2 minutes
- Type IIa
  - fast/moderate
  - medium mitochrondria
  - mixed aerobic / anaerobic
  - 10 minutes

- Type I
  - slow
  - many mitochondria
  - aerobic
  - distance running / swimming / cycling
  - hours

1.4 Fibre Composition in Athletes

- distance runners
  - 75% Type I
  - 25% Type II
- sprinters
  - 25% Type I
  - 75% Type II
- non-athletes
  - 50% Type I
  - 50% Type II

1.5 Respiratory System

- functions
  - manage arterial O_2 pressure
  - manage CO_2 pressure
  - control pH during exercise

1.6 O_2

- haemoglobin in red blood cells carry O_2
  - increase in red blood cells due to endurance training (also blood doping)

1.7 CO_2

- CO_2 produced metabolically
  - aerobic break down of CHO, fats, etc
- CO_2 also produced non-metabolically
  - buffering of acids

$$H^+ + HCO_3 \rightarrow H_2CO_3 \rightarrow CO_2 + H_2O$$

- stops muscles and blood getting too acidic

1.8 Increase in Respiration during Exercise

- increase tidal volume
- increase breathing rate
- at rest
  - 12 breaths / min × 0.5 L/breath = 6 L/min
- maximal exercise
  - 48 breaths / min × 4 L/breath = 192 L/min
- most efficient to increase tidal volume

1.9 Control of Respiration

- initially neural control
- later humoral (blood chemistry) control

1.10 Cardiovascular System

- response to exercise
  - heart pumps harder
  - blood vessels to muscles dilate (double blood flow)
  - decrease blood flow to other organs

$$Cardiac\ Output = Heart\ Rate \times Stroke\ Volume$$

1.11 Heart rate increase

- reduce parasympathetic nerve activity
- increase sympathetic nerve activity
- increase epinephrine
- heart rate from 40bpm to 180bpm
- stroke volume 100 to 150 mL / beat
- endurance athletes can get up to 50 L/min (at 5L/min O_2 consumption)

1.12 Arteriovenous Oxgen Delivery

- measures efficacy of blood in delivering O_2
- get about 6mL of VO_2 for every 100mL of blood at rest
- increases to 20mL of VO_2 for every 100mL of blood at $VO_2\,max$

1.13 Cardiac Output

- at rest
  - 6 L/min
  - 20% to skeletal muscles
- during intense exercise
  - 25 L/min
  - 90% to skeletal muscle
  - dramaticaly decrease % to gut, kidneys, etc
  - maintain flow to brain

1.14 Blood Pressure

- systolic blood pressure can double during intense exercise
- diastolic pressure doesn't change much

1.15 Cardiac Training Adaptations

- lower heart rate at rest and at submaximal exercise
- greater stroke volume at rest and submaximal exercise
- greater maximal cardiac output (due to increased stroke volume)
- increased arteriovascular O_2 difference
  - increased red blood cells
  - more capillaries in muscle
  - more mitochondria
- maximum heart rate doesn't change

1.16 Endocrine System

- Pancreas
  - release of insulin (glucose uptake from cells)
  - release of glucogon (replenish glucose in blood from liver)
- Adrenal
  - epinephrine and norepinephrine
- Pituitary
  - growth hormone

1.17 Endocrine Training Adaptations

- exercise increases bodies insulin sensitivity
  - directly addresses type II diabetes
- epinephrine and norepinephrine increase during exercise
  - regulated by sympathetic nervous system
  - *fight or flight response*
  - increase heart rate, stroke volume, fat mobilisation, glycogen breakdown
- growth hormone
  - increase protein synthesis and FFA utilisation
  - slow but large increase in GH post exercise

1.18 Immune System

- immune system suppressed for hours post intense exercise
  - reduce both antibodies and T-cells
  - epinephrine and cortisol both immunosuppressants

2 Training Adaptations

- endurance training
- strength training

2.1 For endurance training

- frequency
  - 3 to 5 times per week
- intensity
  - 60% - 80% of cardiac reserve (heart rate)
- duration
  - 20 to 60 minutes continuous aerobic
- mode
  - large muscle groups

2.2 For strength training

- frequency
  - 5 times / week, sometimes split routines
- intensity
  - 70% of one repetition maximum (1-RM)
- no of sets
  - 3 sets
- repetitions

- 10 per set

- get neural adaptations first, follwed by muscle hypertrophy
- genetics, nutrition, environmental factors all play role
- percentage strenght gain same for men and women
  - though more testosterone in men

2.3 Nutritional Requirements - Eudurance

- how much to eat
  - maintain energy balance
- what to eat
  - ~60% CHO (endurance)

- when to eat
  - to replenish CHO stores, best within 1-2 hours post exercise
  - increased insulin sensitivity
  - pre competition - 3 hours before, 500 Calories or less, mostly CHO
- maintain hydration during exercise
  - plasma volume
  - temperature regulation

2.4 Nutritional Requirements - Strength

- muscle protein synthesis > protein breakdown
- resistance training + high protein diet
- double protein intake to 1.6kg / kg body weight
- ingest protein in first hour post training
  - easily digested proteins (e.g. whey) ideal

3 Causes of Muscle Fatigue

- causes diverse, but mostly in the muscle
- depends on type of muscle fibre

3.1 Fatigue for Short High Intensity Exercise

- depletion of ATP and PCr
- increased muscle acidity
  - H^+ interferes with Ca^{2+}'s role in muscle contraction
  - also inhibits anaerobic glycolysis
  - buffering (e.g. $NaHCO_3$)

3.2 Fatigue for Endurance Exercise

- decrease in muscle and liver glycogen
- decrease in intra-muscular calcium
- higher body temperature
  - more blood to skin for cooling

3.3 Causes of Muscle Soreness

- muscle soreness felt during and immediately after exercise
  - localised pain and burning
  - prolonged isometric contraction
  - muscle tension causes local blood flow to collapse
  - interupts O_2 delivery
  - increase reliance on anaerobic production
  - increased acidity
  - activate pain receptors in muscle
  - subsides rapidly after exercise stops

- muscle cramps and spasms
  - *electrolyte imbalance caused by dehydration and temperature increase*

- makes neuromuscular junction more excitable
- *altered neuromuscular control*
- motor neuron fires involuntarily
- strecthing golgi tendon organ inhibits motor neurons

- muscle stiffness felt 8-48 hours post exercise
  - delayed onset muscle soreness
  - after performing novel type of exercise
  - caused by eccentric muscle contractions
  - fewer fibres recruited for these actions
  - greater force per fibre leads to micro-trauma
  - leads to inflammation and tenderness
  - not due to lactic acid (lactic acid quickly flushed after exercise)
  - dead muscle removed and replaced over days

3.4 Performance Enhancing Drugs

- ergogenic techniques
  - anabolic steroids

3.5 Strength - Anabolic Steroids

- along with heavy resistance training and high protein diet
  - but without androgenic effects
- administered orally and injected
  - stacking and pyramiding
- enter nucleus and alter gene expression

- serious health consequences
  - cancers
  - psychological effects
  - etc
- also growth hormones
- similar chemical structure to testosterone

3.6 Performance Enhancing Drugs - Endurance

- blood doping
  - O_2 delivery - endeavours near $VO_2\,max$
  - increase red blood cell concentration and blood volume
  - red blood cell reinfusion
  - high altitude exposure
  - EPO (hormone secreted by the kidneys that promotes red blood cell production in the bone marrow). Can lead to blood clots

3.7 Caffeine

- greater mental alertness
- greater fat mobilisation
- greater time to exhaustion
- also interacts with Ca^{2+} from SR

4 Exercise in Health and Disease

- dieting and weight control
- heart disease
- diabetes
- cancer
- successful aging
- mental health

4.1 Health Dangers

- low fitness
- smoking
- systolic BP $>$ 140mmHg
- Cholesterol $>$ 6.2 mM / L
- BMI $>$ 27

4.1.1 even low levels of exercise are beneficial

4.2 Diet, Weight Control, and Exercise

- culprit is adipose cells that store fat
- measures of body composition
  - DEXA (gold standard)
  - skin fold calipers along with hip and waist measurements
  - bio-electrical impedance
  - BMI (pretty crude)

4.3 Types of Body Fat

- Upper body obesity
  - primarily adominal region
  - greater health risk
  - visceral fat within abdominal cavity surrounding liver, pancreas, intestines, etc
- Lower body obesity
  - primalily hips and thighs
  - lower health risk
  - sub-cutaneous

4.4 Metabolic Syndrome

- increased risk for
  - heart disease
  - stroke
  - diabetes type II
- symptoms such as
  - increased bloop pressure
  - high blood glucose
  - abnormal blood cholesterol levels

4.5 Dieting

- dieting alone
  - initial weight loss due to water
  - followed by significant loss of fats
  - *but* also protein, so loss of skeletal muscle
- exercise alone
  - number of Calories burned is relatively small
  - but even is weight loss is minimal, health gains can still be significant

4.6 Heart Disease

- atherosclerosis
  - deposition of plaques of fat on inner walls of arteries
- LDL is major culprit here
  - exercise helps swap HDL for LDL
- heart attacks and stroke
- exercise reduces both systolic and diastolic BP
- physical activity addresses many of the risk factors

4.7 Exercise and Diabetes

- type II diabetes linked with obesity (visceral fat)
  - insulin resistance
  - normal blood sugar < 5.5 mM/L
  - prediabetic < 7mM / L
  - diabetic > 7mM / L

- symptoms
  - thirst
  - frequent urination
  - fatigue
  - slow healing sores and frequent infection

- blurred vision
- loss of peripheral sensation

4.8 Cellular Mechanism of Diabetes

- insulin resistance
- insulin receptor in cell wall opens GLUT4 glucose channel
- in diabetes, signal between insulin receptor and glucose channel is compromised
- single bout of exercise reduces blood glucose
- regular exercise increases glucose sensitivity in muscle
  - both for endurance and strength training

4.9 Exercise and Cancer

- lower risk of some cancers, and helps treatment
- has shown exercise reduces risk for breast, colon, prostate, ~~lung~~ cancers
- exercise enhances natural immunity
- increase levels of anti-oxidants
- lowers obesity
- retards growth factors implicated in cancer such IGF-1

5 Exercise and Aging

- as we've seen, exercise addresses many health issues that arise in aging
- balance, strength, flexibility, endurance
- VO_2 *max* declines with age, exercising mitigates this
  - *athletes* 75 mL / kg / min to 45 mL / kg / min at age 75
  - *sedantary* 40 mL / kg / min to 26 mL / kg / min at age 75
  - **and** never too old to start

5.1 Sarcopenia

- loss of muscle mass with age
  - can lose %10 per decade
- effects strength, balance, etc
  - also impacts bone density
- training adaptations we've discussed before will also occur in older people

5.2 Osteoporosis

- loss of calcium from bones
- bone is similar to muscle in that when overloaded it will adapt and strengthen
- weightlifting especially beneficial

5.3 Exercise and the Brain

- increase cognitive function
- decrease risk of dementia
- decrease risk of Alzheimer's
- decrease risk of Parkinson's
- reduce depression, stress, anxiety

5.4 Healthy Brain

- regular exercise
- healthy diet
- quality sleep
- active social life
- stress management
- mental stimulation

5.5 Brain Activity

- blood flow can increase by up to 20% during exercise
  - mitigates vascular degeneration in the brain
- pretty much all brain areas
- increased blow (and CSF) flow reduces build-up of β amyloid plaques (AD)
- exercise promotes dopamine, benefits people with Parkinson's

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