Unit 3: Exercise

See topic and resource guide for readings, activities

Bibliographic note: In addition to Campbell et al., information for this unit comes from the following sources, all published by Benjamin Cummings

Donatelle, Rebecca J., 2004. *Access to Health, 8/e*
Johnson, Michael D., 2003. *Human Biology: Concepts and Current Issues, 2/e.*
Martini, Frederick. *Anatomy & Physiology, 5-6/e.*
Powers, Scott K. and Stephen L. Dodd, 2003. *Total Fitness and Wellness, 3/e.*

I. Background: Physical fitness and exercise
   A. Being physically active has numerous health benefits – they include
      1. reduced risk of heart disease
      2. reduced risk of developing Type II diabetes
      3. reduced risk of developing high blood pressure or reduced blood pressure if already high
      4. reduced risk of colon cancer
      5. reduced risk of feelings of depression/anxiety
      6. decreased LDL (“bad cholesterol”)
      7. increased HDL (“good cholesterol”)
      8. weight control
      9. building and maintaining healthy bones, muscles and joints
      10. improved immune functioning
      11. in older adults, improved movement and decreased risk of falling
      12. increased psychological well-being
   B. Americans as a whole are not sufficiently active
      1. According to CDC stats from 1986-2000:
         a. 26.2% of Americans got the recommended amount of exercise:
            (1) Leisure-time physical activity at least 5 times per week for 30 minutes each time or
            (2) At least 20 minutes of vigorous activity 3 times per week
            (3) or both
            (4) (Note: more is better!)

b. 27.6% of Americans were inactive = no leisure-time physical activity within the last month
c. 46.2 were insufficiently active: between a and b

2. Activity levels vary strongly with age, gender, ethnicity, education, income, region, and more. E.g.: (CDC http://apps.nccd.cdc.gov/PASurveillance/DemoComparev.asp?Year=2001)

	Female					Male				
	18-24	25-34	35-44	45-64	65+	18-24	25-34	35-44	45-65	65+
recommended	52.0	47.2	45.4	41.7	27.3	66.8	65.6	49.2	47.4	45.9

	Recommended	Insufficient	Inactive
Hampton Roads	50.4	35.8	13.8
Richmond	45.9	39.9	14.2
Tucson	57.5	34.3	8.2

C. Physical fitness is defined by the US Department of Health and Human Services as "**a set of attributes that people have or achieve that relates to the ability to perform physical activity**" – it has 5 components (CDC: Components of Physical Fitness):

1. **Cardiorespiratory endurance** = cardiorespiratory fitness
   a. Refers to body's ability to supply fuel (oxygen, nutrients) during sustained physical activity.
   b. Requires healthy heart, circulatory system, lungs, and respiratory muscles
   c. This component of fitness has the most wide-ranging health benefits
2. **Muscular strength** = ability of muscle to exert force during an activity
3. **Muscular endurance** = ability of muscle to continue to perform without fatiguing

4. **Body composition**
    a. Refers to the relative amounts of muscle, fat, bone, and other vital parts of the body
    b. BMI is a rough way to estimate body fat composition (but makes simplifying assumptions about proportion of muscle)
    c. > 25% body fat (men) or 30% body fat (women) = obese
    d. Recommendation is < 17% (men) and 24% (women)
    e. Increasingly, attention is being paid not just to total body fat but distribution as well; intra-abdominal fat (fat inside the abdominal cavity around the internal organs) may be more problematic than fat just under the skin (subcutaneous fat)
5. **Flexibility** = range of motion around a joint

D. Exercise improves all 5 components of physical fitness
    1. For simplicity, divide exercise into two broad categories:
        a. **Aerobic/endurance** = any activity that elevates heart rate and can be sustained at moderate levels of exertion for extended periods of time
        b. **Strength/resistance** = working muscles against heavy resistance, usually for very limited periods of time ("low repetitions, high resistance")

2. Which types of exercise improve which aspects of fitness (this is a "big-picture" view)?

	Type of Exercise	
Fitness Component	**Aerobic**	**Strength**
cardiorespiratory	yes	limited
muscular strength	limited	yes
muscular endurance	yes	limited
body composition	some	yes
flexibility	depends on activity	limited

3. A more detailed look at the benefits of each type of training:
   a. Aerobic/endurance:
      (1) increased endurance, overall "energy"
      (2) increased aerobic capacity (including ability of muscles to burn fat)
      (3) improved muscle tone (but not size or strength)
      (4) can get a decrease in body fat composition
   b. Strength/resistance:
      (1) decreased incidence of joint/muscle injuries (strengthening muscles stabilizes joints)
      (2) decreased lower back pain (strengthening postural muscles)
      (3) increased muscle definition, size, tone
      (4) increased proportion of lean muscle mass (increases BMR)
      (5) improves bone density, decreasing the risk of osteoporosis

E. To understand how exercise confers these benefits, we need to understand skeletal muscle structure and function, then apply those concepts. To that end, we'll look at
   1. Structure of muscles
   2. How muscle contraction is controlled

3. How muscles use energy under different conditions
4. Putting it all together: understanding
    a. What happens with energy during a moderate aerobic workout
    b. The role of aerobic and strength training in weight loss/weight control
    c. National recommendations for aerobic exercise, including frequency, intensity and duration to improve cardiorespiratory health

F. *Summary:*

1. Physical fitness confers many benefits, including reducing the risk of cardiopulmonary and other kinds of diseases and improving many aspects of physical and mental well-being.

2. Americans as a whole are insufficiently physically active; physical activity levels vary strongly with factors such as age, gender, ethnicity, education, income, and region.

3. Physical fitness has 5 components: cardiorespiratory endurance, muscular strength, muscular endurance, body composition, and flexibility.

4. A combination of aerobic/endurance and strength/resistance training can improve all 5 components of physical fitness, with each type of training conferring a range of specific benefits.

II. Skeletal muscle structure and function

A. Whole muscles are a partnership of
    1. contractile and connective tissue (muscle and tendons)
    2. nervous tissue (nerve cells controlling muscle contractions)
    3. blood supply (capillary beds, through which blood delivers oxygen, nutrients)

B. Muscle tissue is hierarchically organized:
    1. The whole **muscle** is composed of
        a. bundles of muscle cells (fascicles) made up of
            (1) individual **muscle cells = muscle fibers**, made up of
                (a) bundles of contractile protein = myofibrils

C. Muscle contraction is stimulated by signals from nerves

1. The type of nerve that stimulates skeletal muscle is called a **motor neuron**
2. Motor neurons can branch to many individual muscle fibers
   a. 1 motor neuron + all the muscle fibers it stimulates = 1 **motor unit**
3. For large muscles, we can vary the amount of power we generate by varying the number of motor units we "recruit" to contract – e.g., lifting a pencil vs. lifting a barbell
   a. You use fewer motor units for the pencil than the barbell
   b. But even with the barbell, you can increase power and force beyond what's strictly necessary to lift by "squeezing" the muscles (adding isometric contraction)
4. Muscles vary in the number of muscle fibers per neuron in each motor unit – the more precision and control we need, the fewer fibers/neuron
   a. In a large muscle like the biceps, a motor unit may consist of several hundred fibers
   b. In the muscles controlling eye movement, each motor neuron controls a single muscle fiber
5. Fun factoid: Botox eliminates wrinkles by interfering with nerve signals to the muscles
   a. The active ingredient is a bacterial toxin = botulinum toxin (which causes severe food poisoning if it's ingested).
   b. The toxin prevents nerves from sending signals to muscles.
   c. Injected into facial muscles, prevents them from contracting, so it smooths wrinkles.
   d. Effects last 3-6 months.
   e. Interesting new finding – some plastic surgery patients who also suffer from migraines reported improvements in their headaches – this is an area of very active research!

D. Muscles require energy both to contract and relax
   1. As usual for cellular activities, energy released from ATP is what actually

powers contraction & relaxation: ATP -> ADP + energy -> muscle activity

2. An individual muscle fiber contracting rapidly may use 37.5 trillion ATP molecules per second (and a whole muscle has thousands of fibers!).
   a. Muscle cells can't store that much ATP – so where does it come from?
3. Muscles use a variety of energy sources and pathways:
   a. At rest, muscles use aerobic respiration of fatty acids to generate ATP
      (1) A very small amount (~ 10 seconds worth) is maintained in the cell as ATP
      (2) More is stored in the form of a molecule called **creatine phosphate**:
         (a) With the input of energy, creatine can "receive" a phosphate and form a high-energy phosphate bond
         (b) That "high-energy phosphate" can then be used to convert ADP to ATP
         (c) Summarizing the reactions (remember that, at rest, cells are generating ATP by aerobic respiration):
            i) aerobic respiration -> ATP + creatine -> creatine phosphate (energy stored) + ADP
            ii) ADP + creatine phosphate -> ATP – this can then be broken down by the muscles to power activity
         (d) Cells store enough energy as creatine phosphate to last about 30 seconds
   b. When muscle cells start to contract:
      (1) They first use up their ATP (10 seconds)
      (2) Then they use up their creatine phosphate (30 seconds)
      (3) Then they have to start increasing the rate of cellular respiration – the idea is for them to generate ATP as fast as they're using it
         (a) The first source of energy for respiration will be glycogen stored in the muscles – this usually only lasts 3-5 minutes

(b) When that's gone, glucose and fatty acids delivered by the blood will supply energy for respiration

c. The oxygen supply to the muscles will determine how much ATP muscles will be able to get from cellular respiration
   (1) If muscles have a good oxygen supply (delivered by the circulatory system), they'll use aerobic respiration – starting with stored glycogen as fuel, then converting to glucose and fatty acids delivered with the blood
   (2) If muscles don't have a good oxygen supply, they have to use anaerobic respiration – again starting with stored glycogen, then converting to glucose (but not fatty acids!) delivered by blood – this usually can't last, though (think about why not)

d. Muscles fatigue (lose their ability to contract) when ATP production can't keep up with demand. This can happen when:
   (1) ATP and CP reserves are exhausted during short, intense activity
   (2) cells are physically damaged
   (3) all energy reserves are depleted during very long periods of activity (marathons, e.g.)
   (4) anything that limits circulation or the oxygen supply in the blood
   (5) Note that lactic acid buildup & increasing acidity was once thought to be a cause of muscle fatigue, but that's being increasingly challenged – in fact, acidity may actually help muscles keep performing!

4. Complicating factor – different kinds of muscle fibers are specialized for different kinds of activities, so have different energetic profiles
   a. **Slow oxidative muscle** is specialized for repeated, long contractions
      (1) Fibers are thin, giving them a large SA for oxygen absorption – but there's a trade-off:
         (a) Muscle strength/power is a function of muscle cell diameter – thicker = more powerful

(b) So thin fibers can't provide the most powerful contractions

(2) Fibers have a special form of hemoglobin (myoglobin) to transport oxygen – this gives the muscle fibers a dark color

(3) They also have lots of mitochondria to support aerobic respiration.

(4) So these fibers are specialized for aerobic cellular respiration, which provides the maximum amount of ATP/glucose molecule and allows sustained activity – muscles are less prone to fatigue because they have better ATP supply

b. **Fast glycolytic muscle** is specialized for fast, powerful contraction

(1) "Fast" refers to how quickly they respond to nerve signals by contracting

(2) Fibers are thick, providing more power

(3) But remember the trade-off: thicker fibers have lower SA/V, so can't absorb oxygen as easily

(4) Fibers lack myoglobin, so they're lighter in color

(5) They also have fewer mitochondria

(6) These characteristics mean that, when they're contracting, these muscles will be using anaerobic respiration and generating lactic acid

(7) So, although they can contract rapidly and powerfully, they fatigue more quickly.

(8) These are the muscles you're exercising when you do high-resistance weight lifting – a relatively low number of repetitions using high resistance and working the muscles to "failure"

(9) These are the fibers that are "helped" by creatine supplementation –

(a) Creatine phosphate supplements give these muscles more energy, so they can build more power

(b) They provide "bulk" to the muscles by increasing the amount of water in the muscle

(c) Note that CP supplements don't increase aerobic endurance

c. Most muscles have a mixture of both kinds of fibers

(1) The number of each type of fiber is approximately fixed at birth (but some conversion is possible with appropriate training).

(2) Training can change the size of a muscle fiber (but not the number of fibers) – so training can change the relative mass of each type of fiber – e.g.

(a) Jill Gym Rat's quadriceps have 50% fast and 50% slow fibers. She focuses on strength training, increasing the size of the fast fibers. At the end of a year of dedicated training, her total muscle mass is 70% fast and 30% slow fibers – even though the actual number of each type hasn't changed.

E. Summary

1. *Whole muscles are partnerships of contractile, connective, and nervous tissue along with a blood supply*
2. *Muscle tissue is hierarchically organized. A whole muscle is made of bundles of muscle cells (muscle fibers). Each muscle fiber is made up of bundles of contractile proteins.*
3. *Muscle contractions are stimulated by motor neurons, each of which may stimulate many different muscle cells. One motor neuron and all the fibers it controls is a motor unit. The power we generate with a muscle depends on how many motor units our brains "command" to contract. Muscles involved with fine control and precise movements typically have fewer muscle fibers than do large muscles. Botox eliminates wrinkles by preventing nerve signals from stimulating muscle contractions.*
4. *Muscles require energy in the form of ATP both to contract and to relax.*

Muscles can't store enough ATP to sustain contractions, so they use a variety of energy storage and conversion pathways.

a. *Muscle cells at rest use aerobic respiration to burn fat and generate ATP. Some of that energy is stored as creatine phosphate, which can be used to generate ATP from ADP very rapidly.*
b. *When muscles start contracting, they use their stored ATP and their stored creatine phosphate very quickly.*
c. *When ATP and CP reserves are depleted, muscle cells use cellular respiration to supply the ATP they need. They begin with anaerobic respiration using glycogen; then, if they have an adequate oxygen supply, they switch to aerobic respiration using glycogen first, then fat as the energy supply.*
d. *Muscles fatigue when ATP production can't keep up with demand. This can be caused by many different factors, including ATP and CP depletion, physical damage, and limitations to circulation.*

5. *Different types of muscle fibers are specialized for different energy pathways. Slow oxidative muscle is specialized for repeated, long contractions, but doesn't provide great power. Fast glycolytic muscle is specialized for rapid, powerful contraction but lacks endurance. Creatine Phosphate supplements help this type of muscle fiber. Most muscles are made of a combination of the two types of fibers. Training can increase the size of fibers, but not the number of fibers or the number of each type.*

III. Putting it all together:

A. #1 What happens during a moderate-intensity aerobic workout?

1. The big picture:
   a. Initial energy is provided by anaerobic respiration.
   b. The longer you exercise, the greater the proportion of the energy you use is provided by aerobic respiration.
   c. The longer you exercise, the greater proportion of the fuel for aerobic

respiration is provided by fat rather than carbohydrates

2. A few details:
    a. Anaerobic respiration provides the majority of exercise energy for the first ~ 4 minutes of exercise (this can be increased with appropriate training).
        (1) Note - the reason CP doesn't increase aerobic endurance is that it's used up very quickly – well before muscles are using aerobic respiration to a significant degree
    b. By ~ 20 minutes, aerobic respiration is providing 90% or more of energy used.
    c. Anaerobic respiration uses carbohydrate (glucose, glycogen) as its sole fuel source, so that's what you "burn" during the anaerobic phase.
    d. During the first 15-20 minutes of aerobic exercise, most of the fuel is still coming from carbs.
    e. After ~ 20 minutes, fat is increasingly used; by ~ 50 minutes, fat and carbs are being used equally, then fat predominates
    f. Note that, in general, carbs are an "easier" source of energy for muscles to use, both during exercise & to replace energy stores afterwards – we should still get plenty in our diets!

B. #2: Exercise for weight control
    1. Note that one pound of body fat = 3500 kcal
        a. To lose one pound of fat per week, you need a daily energy deficit of 500 kcal
        b. People who successfully lose weight and keep it off achieve the deficit by combining modest reductions in caloric intake with modest increases in activity – note that this means you're not "dieting"; you're changing your lifestyle!
        c. Healthy weight loss is considered 1-2 pounds/week

2. Both endurance and strength training can affect weight and body composition.
3. Endurance (aerobic) training:
    a. Burns calories
    b. Burns fat during exercise and, over time, improves the ability of skeletal muscles to burn fat as energy
4. Strength training
    a. Reduces muscle loss that may occur during dieting
    b. Increases muscle mass, which increases basal metabolic rate (i.e., you burn more calories even at rest)
5. Note that, the more muscles you use, the more benefit you get
6. Note also that it doesn't matter whether muscles are burning carbs or fat during the exercise itself – for weight control, generating an energy deficit is what matters; your body will burn stored fat to meet its energy needs.

C. #3: Exercising for cardiorespiratory (CR) health
1. Remember that, to maintain cardiorespiratory health, we need good aerobic exercise
2. The basic principle is simple: Aerobic exercise increases oxygen and nutrient demands from the muscles – which stimulates the circulatory and respiratory systems to work harder to meet the demands.
3. Recommended amounts of exercise to improve CR health involve 3 factors:
    a. exercise intensity
    b. exercise duration
    c. exercise frequency
4. Start with the easy factors:
    a. **Frequency**: current CDC and other guidelines are that we should get good aerobic exercise 3-5x per week (3 is minimal; most are recommending something like "most days")

b. **Duration**: This will vary depending on your individual fitness, but general guidelines are
   (1) 20-60 minutes, exclusive of warm-up and cool-down periods, with 30 minutes being a good baseline
   (2) New studies suggest that exercise doesn't have to be done all at once – but increments should be at least 10 minutes long
   (3) Increasingly, recommendations are for longer duration rather than shorter.

5. **Intensity** is more complicated. The basic recommendation is that we should be exercising at "moderate to vigorous" intensity – but what does that mean???
   a. To understand exercise intensity, we need to understand **maximum aerobic capacity** (MAC for our purposes) = the maximum ability to transport and use oxygen during heavy (not sustained) exercise
   b. The **intensity** of exercise is measured as the proportion of MAC it requires.
   c. Exercise intensity affects muscle energetics: at exercise intensities of ~60% MAC, muscles begin to switch over to anaerobic respiration (why would this be?)
   d. So, for exercise to be aerobic and to improve cardiorespiratory health, it should be kept to 50-85% MAC. This corresponds to "moderate-vigorous" intensity
   e. How we measure MAC and determine our actual exercise intensity? Technically, it's very difficult because it requires specialized equipment. So we use various substitute measures
      (1) **Target Heart Rate** (THR)
         (a) The principle for substituting THR for MAC is simple: the maximum ability to transport oxygen (MAC) is a function, in part, of the ability of our heart to pump blood – and that is, in

part, a function of heart rate.

(b) a THR of 70-90% of maximum heart rate is about equivalent to 50-85% MAC (that's a range from moderate to vigorous intensity)

(c) maximum heart rate is calculated as 220-age for women, 226-age for men

(d) Example:

(e) my maximum heart rate (in theory!) = 220-48 = 172 beats/minute

i) so my THR during aerobic exercise is 70-90% of 172 = 121-156 beats/minute

(2) An even simpler way to measure (roughly) exercise intensity = the "**talk test**"

(a) The premise is similar to the premise for THR: the ability to deliver oxygen is, in part, a function of how fast and hard we're breathing.

(b) The test is:

i) If you can sing and perform the exercise, you are at a very low level of intensity

ii) If you can carry on a conversation (talk) without losing your breath while performing the exercise, you are at a moderate level of intensity

iii) If you can't talk normally, you are at a vigorous level of activity

(3) Finally, the CDC has guidelines for measuring intensity by the rate at which you burn calories during exercise:

(a) 3.5-7 kcal/minute = moderate intensity

(b) Above 7 kcal/minute = vigorous intensity

(c) These are useful measurements if you're working out on

exercise equipment that records time and calories (the calories reported are kcal)

(4) Note that these are only very general guidelines – individuals will vary based on age, gender, level of fitness, and many other factors.

6. So putting it all together:
   a. The recommended amount of physical activity for improving CR health is 20-60 minutes of moderate-vigorous activity 3-5x per week.
   b. Remember that you should consult with a physician before beginning a new exercise program – especially if you have been fairly sedentary and/or have other health issues

D. Summary:

1. During a moderate-intensity aerobic workout, muscles begin with anaerobic respiration using carbohydrates for energy. After about 4 minutes, they begin switching to aerobic respiration; by about 20 minutes, aerobic respiration is providing 90% or more of the energy muscles need. Fats become increasingly used for energy after about 20 minutes of exercise and predominate after about 50 minutes.

2. The current prescription for weight control is to combine modest calorie reduction with increases in activity. Both strength/resistance and aerobic/endurance training contribute to weight control/weight loss.

3. To maintain cardiorespiratory health we should aim for 20-60 minutes of moderate-vigorous activity 3-5 times per week. Intensity is measured as a fraction of the maximum aerobic capacity; moderate-vigorous activity corresponds to about 50-85% of MAC. We can estimate exercise intensity using target heart rate, the talk test, and/or measures of the number of calories burned per minute of activity.