Physical Ergonomics: Work Physiology

Sections:

1. Human Physiology
2. Muscular Effort and Work Physiology

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by Mikell P. Groover, ISBN 0-13-140650-7.

Physical Ergonomics - Physiology

- **Physical Ergonomics** – concerned with how the human body responds to physical work activity (work physiology) and how the physical dimensions of the human body affect the capabilities of a worker (anthropometry)

- **Physiology** - a branch of biology concerned with the vital processes of living organisms and how their constituent tissues and cells function
  - Important in work because work requires functioning of the tissues (muscles, ligaments, bones) needing expenditure of physical energy

Human Physiology

- Human musculoskeletal (muscles and bones) system
  - Primary actuator for performing physical labor and other activities requiring force and motion
  - Composed of muscles and bones connected by tendons
    - 206 bones in human body: provide protection for vital organs (skull), a framework for physical activity (bones in the legs)
    - Energy to perform physical activity provided by metabolism
  - Bones are connected to each other at their joints by means of ligaments.

Joint Types for Body Movement

1. Ball-and-socket – shoulder and hip joints
2. Pivot – neck
3. Hinge – elbow and knee

- Ball-and-socket joints can apply greater force than pivot joint

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Muscle Types

- Cardiac muscles: heart muscles that performs the pumping function for the cardiovascular system

- Smooth muscles: in the intestines they accomplish peristalsis for food digestion, in the blood vessels they serve in the regulation of blood flow and pressure

- Skeletal muscles

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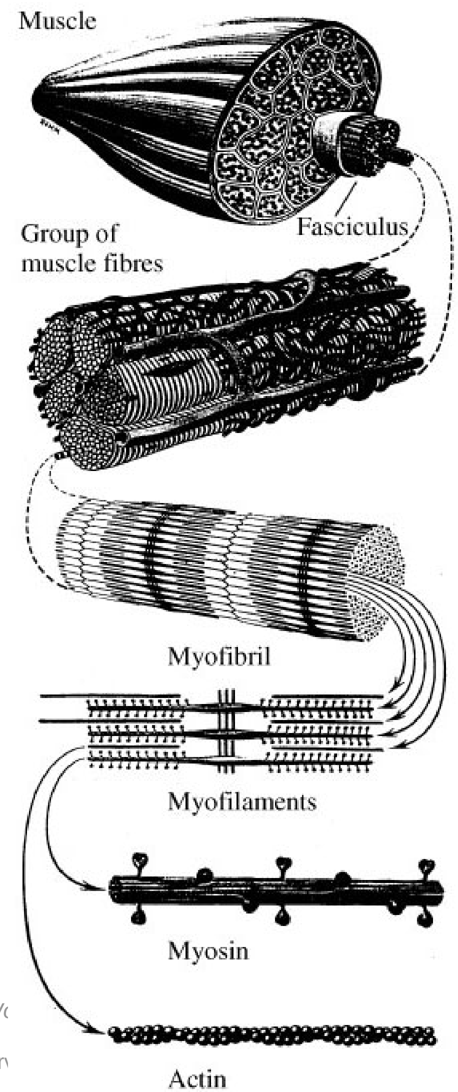
Skeletal Muscles

- Provide power for force and motion in the musculoskeletal system
- Approximately 400 skeletal muscles, 40 percent of human body weight
- They are attached to the bones by tendons
- Blood vessels and nerves distributed throughout muscle tissue to deliver fuel and provide feedback

The structure of a muscle

Flesh tissue- bundles of long cells

- Muscle fibers (0.1 mm-140mm): connective tissue to the bones, blood vessels, nerves
- Myofibril
- Protein filaments
  - Myosin: thick filaments – long proteins
  - Actin: thin filaments – globular proteins
  - Two types are interlaced to contract (physical condition of the muscle when it is activated)



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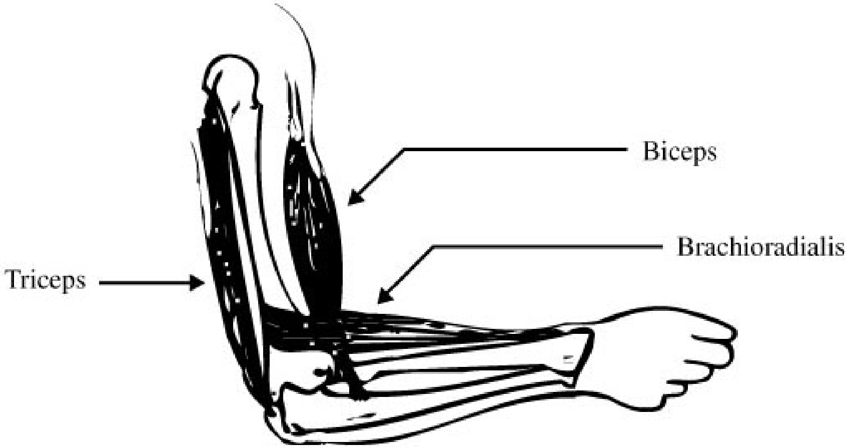
Skeletal Muscle Contractions

- Concentric muscle contraction – muscle becomes shorter when it contracts
- Eccentric muscle contraction – muscle elongates when it contracts
- Isometric muscle contraction – muscle length stays the same when it contracts

Skeletal Muscle Contraction

- Skeletal muscles are organized in pairs
  - Act in opposite direction about the joints that are moved by them



- Open the elbow joint
  - Triceps -> shorter (concentric c.), biceps->longer (eccentric c.)
- Close the angle of the elbow joint
  - Triceps -> longer, biceps->shorter
- To hold an object in a fixed position
  - Both contract isometrically

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Metabolism

- Muscle contraction is enabled by the conversion of chemical energy into mechanical energy, the process is called **metabolism**.
- Sum of the biochemical reactions that occur in the cells of living organisms
- Functions:

1. Provide energy for vital processes and activities, including muscle contraction
2. Assimilate new organic material into the body

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Metabolism

- Can be viewed as an energy rate process
  - The amount of energy per unit time at which chemical energy (contained in food) is converted into mechanical energy / the formation of new organic matter.
- Energy unit: kilocalorie (kcal)-the most commonly used one, kilojoule (kJ), Newton-meter (Nm), British thermal unit (Btu)
- Energy rate unit: kcal/min-the most commonly used one, kJ/min, Nm/min, Btu/min

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Types of Metabolism

- Basal metabolism – energy used only to sustain the vital circulatory and respiratory functions: the rate at which heat is given off by an awake, resting human in a warm location at least 12 hours after eating
- Activity metabolism – energy associated with physical activity such as sports and manual work
- Digestive metabolism – energy used for digestion

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Total Daily Metabolic Rate

- Daily metabolic rates:

$$TMR_d = BMR_d + AMR_d + DMR_d$$

where

TMR_d = total daily metabolic rate, kcal/day;

BMR_d =daily basal metabolic rate, kcal/day;

AMR_d =daily activity metabolic rate, kcal/day;

DMR_d =daily digestive metabolic rate, kcal/day

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Total Daily Metabolic Rate: How to estimate components?

- The basal metabolic rate: depends on the individual's weight, gender, heredity, percentage of body fat, etc.
  - For a 20-year old male, BMR_h//kg: 1.0 kcal per kg of body weight
  - For a 20-year old female, BMR_h//kg: 0.9 kcal per kg of body weight
  - Age correction: subtract 2% for each decade above 20 years
- The activity metabolic rate: will be discussed
- The digestive metabolic rate:

$$DMR_d = 0.1\ (BMR_d + AMR_d\ )$$

Example: Daily Metabolism Rate

- **Given:** a 35 year old women who weights 59 kg.
- **Determine:** The daily basal metabolism rate.
- **Solution:**

  She is 1.5 decades older than 20 year

  Age correction: 1.5(0.02)=0.03

  BMR_h/kg=0.9(1-0.03)=0.873kcal/hr/kg of body weight

  For 24 hours:

  BMR_d=0.873(59)(24)=1238 kcal/day

  BMR_m=1238/((24)(60))=0.86 kcal/min

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Biochemical Reactions in Metabolism

- The liberation of chemical energy from food starts in the digestive track
- Food categories:
  - Carbohydrates (4 kcal/g) – converted into glucose ($C_6H_{12}O_6$) and glycogen
    - Primary source of energy muscle
    - Glycogen is stored in the muscles and changed into glucose as needed
  - Proteins (4 kcal/g) – converted into amino acids
  - Lipids (9 kcal/g) – converted into fatty acids (acetic acid and glycerol)

Muscle Strength and Endurance

- Apart from energy expenditure, another important factor is strength:
  - the maximum torque that a given muscle can exert voluntarily about the skeletal joint
  - the maximum force that can be applied by a muscle
- Static strength – human subject applies as high a force as possible against an immovable object
  - Duration of test is short (e.g., a few seconds)
  - Results influenced by joint type (arm vs. leg) and joint angle
- Dynamic strength – tested under conditions that involve changes in joint angles and motion speed

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Static vs. Dynamic Muscular Activities

	Static muscular activity	Dynamic muscular activity
Description	Sustained contraction	Rhythmic contraction and relaxation
Examples	Holding a part in a static position Squeezing a pair of pliers	Cranking a pump handle Turning a screwdriver
Physiological effect	Reduced blood flow to tissue restricts oxygen supply and waste removal. Lactic acid is generated. Metabolism is anaerobic.	Adequate blood flow allows oxygen supply and waste removal needs to be satisfied. Metabolism is aerobic.

- Dynamic muscle effort is physiologically less costly to the muscles compared to the static effort

Factors Affecting Strength

- The static strength differences between the strongest and the weakest workers can be as much as 8 to 1.
- Size (e.g., height, body weight, build)
- Gender
  - Average strength of females is 67% of the males'
- Age
  - Maximum strength at age 25 to 35
  - About 80% of peak in mid-fifties
- Physical conditioning
  - Physical exercise can increase strength by as much as 50 percent

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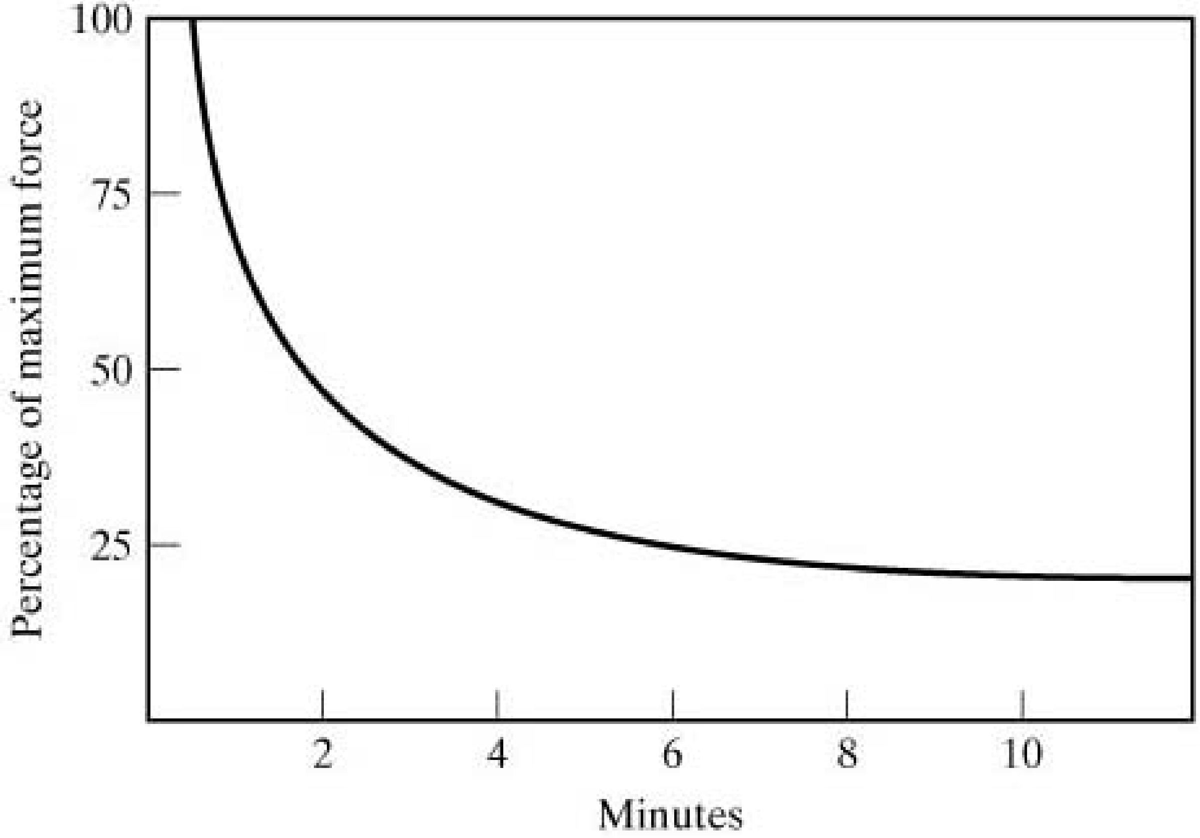
Muscle Endurance

- Muscle endurance is defined as the capability to maintain an applied force over time
  - Ability to maintain maximum static force lasts only a short time
  - After about 8 to 10 minutes, a person can only apply about 23% of maximum static force achieved at beginning of test

Muscle Endurance



Dynamic Muscle Activity vs Static Force

- Dynamic muscle activity (requiring dynamic force application) in a repetitive motion cycle
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    - Muscle fatigue - applied dynamic force declines over time (a similar curve)
    - The decline is slower than in the case of an applied static force: the bottom level is higher than 23%.

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