Physical Ergonomics: Work Physiology and Anthropometry

Chapter 23

Sections:

1. Human Physiology
2. Muscular Effort and Work Physiology
3. Anthropometry

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Physical Ergonomics - Physiology and Anthropometry

- **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
- **Anthropometry** – a branch of anthropology concerned with the dimensions of the human body, such as height and reach
  - Important in work because the dimensions of the human body affect capabilities of worker and are essential in designing her workspaces

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.

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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

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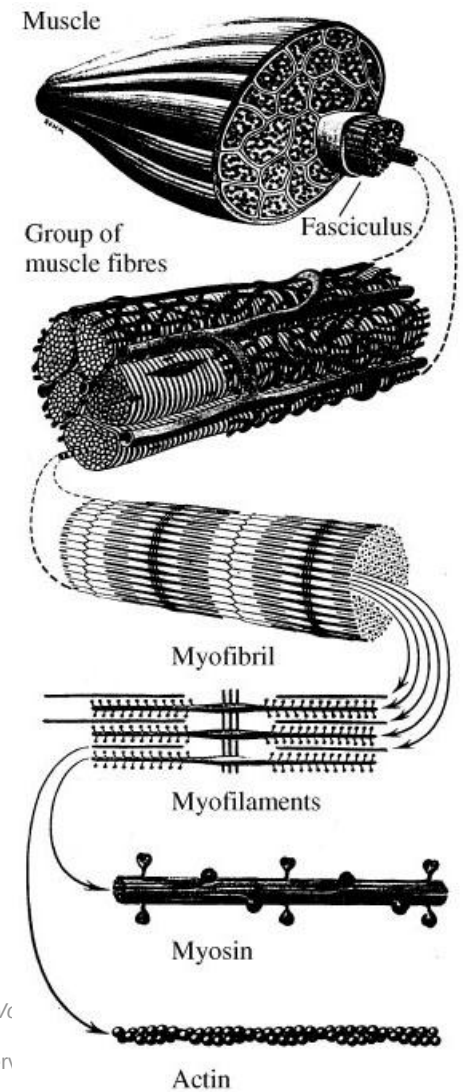
The structure of a muscle

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)



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

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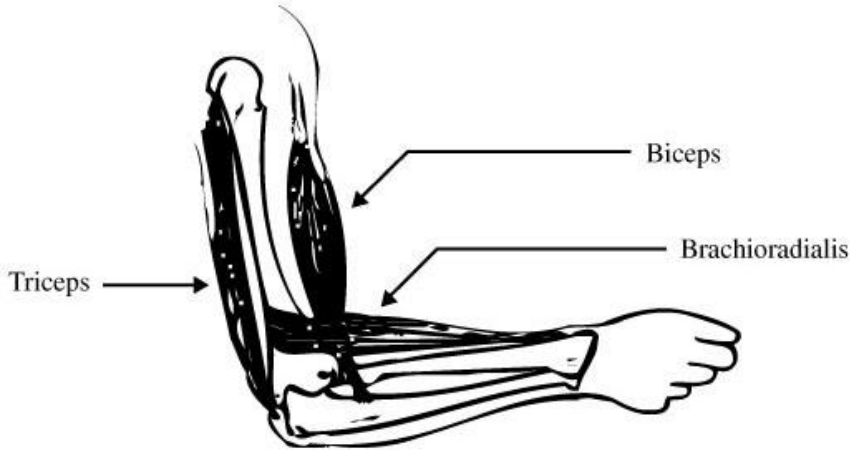
Skeletal Muscle Contraction

- 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

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

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

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:

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

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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

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)

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Energy Requirements for Muscle Contraction

- Two phosphate compounds stored in the muscle tissue
  - ATP - adenosine triphosphate ($C_{10}H_{16}N_5P_3O_{13}$)
  - CP- creatine phosphate ($C_4H_{10}N_3PO_5$)

- Energy used for muscular contraction – hydrolysis: ATP's one of the triphosphate bonds is broken to form ADP (adenosine diphosphate, $C_{10}H_{15}N_5P_2O_{10}$)

$$ATP + H_20 \rightarrow ADP + energy$$

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For muscle cells to continue to be supplied with energy

- ADP must be converted back to ATP
- 3 possible mechanisms
  - The use of CP: the fastest way, but energy generating capacity of CP is limited

    ADP + CP + energy $\rightarrow$ ATP

  - Glycolysis: glucose $\rightarrow$ pyruvic acid $\rightarrow$ energy used in conversion of ADP to ATP
    - Aerobic Glycolysis (aerobic metabolism): with oxygen - pyruvic acid is oxidized to form carbon dioxide and water
    - Anaerobic Glycolysis (anaerobic metabolism): without oxygen

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Aerobic Glycolysis

- Glucose reacts with oxygen to form carbon dioxide and water, releasing energy in the process

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

Anaerobic Glycolysis

- Occurs when insufficient oxygen is available and the reaction produces lactic acid (from the pyruvic acid)

- Aerobic versus anaerobic glycolysis:
  - Aerobic glycolysis produces about 20 times the amount of energy as anaerobic
  - Accumulation of lactic acid in muscle tissue is a principal cause of muscle fatigue, weakness, and muscle pain

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Delivery of oxygen

- Is a key factor in metabolism.
- Oxygen is captured from the air by respiratory system.
- Delivery of oxygen (as well as delivery of glucose and other nutrients) is accomplished by cardiovascular system.

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Cardiovascular System

- **Heart** - the pump that drives the circulation of blood throughout the body
  - Blood : Plasma (55% of volume) and three types of blood cells (45% of the volume) (1) red blood cells (carry oxygen and carbon dioxide), (2) white blood cells, (3) platelets

- **Arteries** - deliver oxygen, glucose, & other nutrients from lungs and digestive tract to muscle tissue and organs

- **Veins** - deliver carbon dioxide & waste products to lungs, kidneys, and liver

- **Capillaries** - small blood vessels between arteries and veins to exchange nutrients and waste between blood and tissue

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Respiratory System

- Nasal cavity (nose) - inhales air (oxygen) and exhales carbon dioxide
- Air passageway connecting nasal cavity and lungs
- Lungs - consist of alveoli (air-containing cells) that provide for exchange of gases in the blood circulating through them
  - 200 to 600 million alveoli in adult human lungs
  - Surface area = 70 to 90 m^2 (750 to 970 ft^2)

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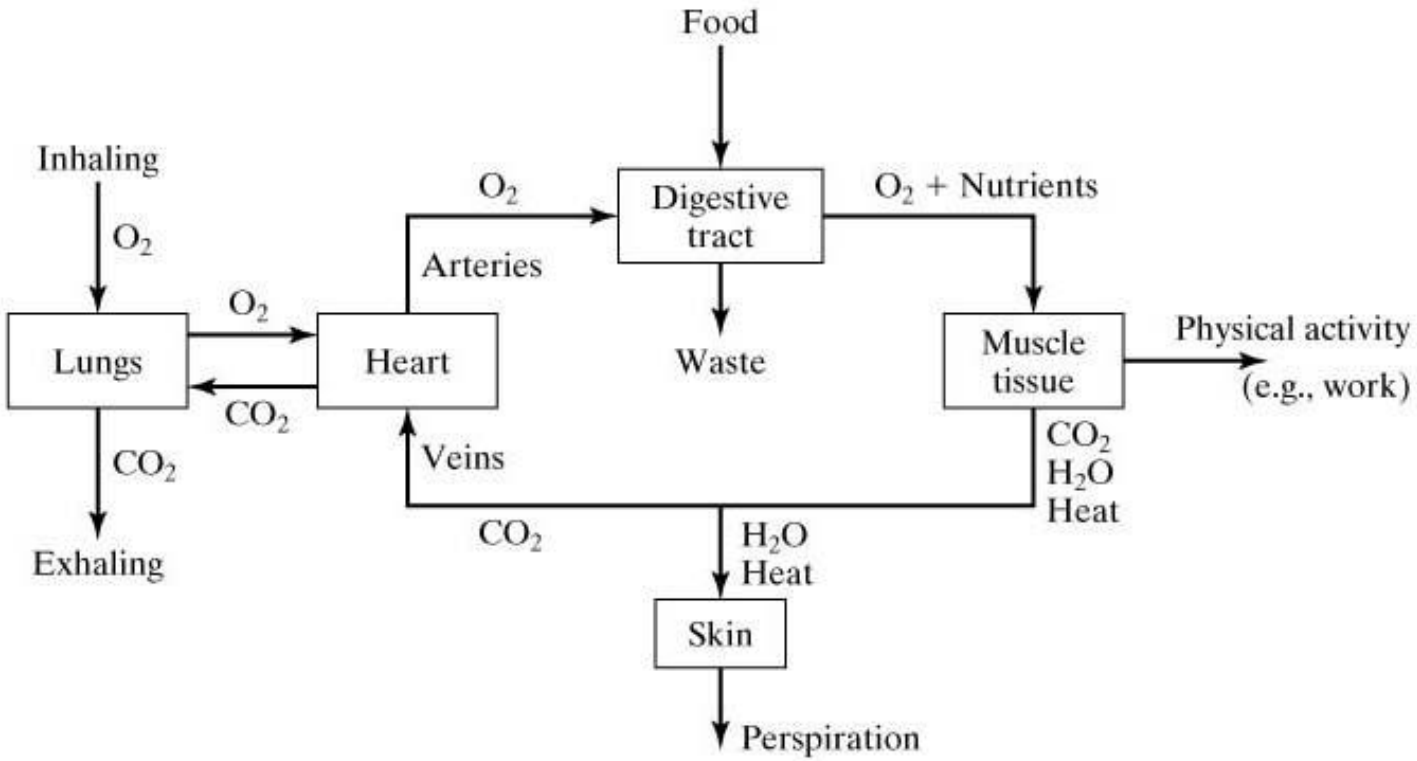
Respiratory and Cardiovascular Systems



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Greater Muscular Effort

- Physical demands on the human body increases: Respiratory system and cardiovascular system must work harder
  - Heavier breathe, faster heart beat: to distribute the greater amount of oxygenated blood to the muscle tissue and return the waste
  - Increased blood pressure: more blood is distributed
  - Increased body heat - perspiration : metabolic processes' efficiency is much less than 100% (~20-30%)

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Muscular Effort and Work Physiology

- Capacity of human body to use energy and apply forces depends on :

1. Capacity of cardiovascular and respiratory systems to deliver required fuel and oxygen to muscles and carry away waste products

2. Muscle strength and endurance (depends on cardiovascular and respiratory limitations)

3. Ability to maintain proper heat balance within the body

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Cardiovascular/Respiratory Capacity and Energy Expenditure

- Oxygen consumption and heart rate are proportional to energy expenditure in physical activity
  - 4.8 kcal of energy expenditure requires an average of one liter of O_2 (= 4.5 l. of air)

- As physical activity becomes more strenuous, energy expenditure increases, and so does oxygen consumption (=respiration rate) and heart rate

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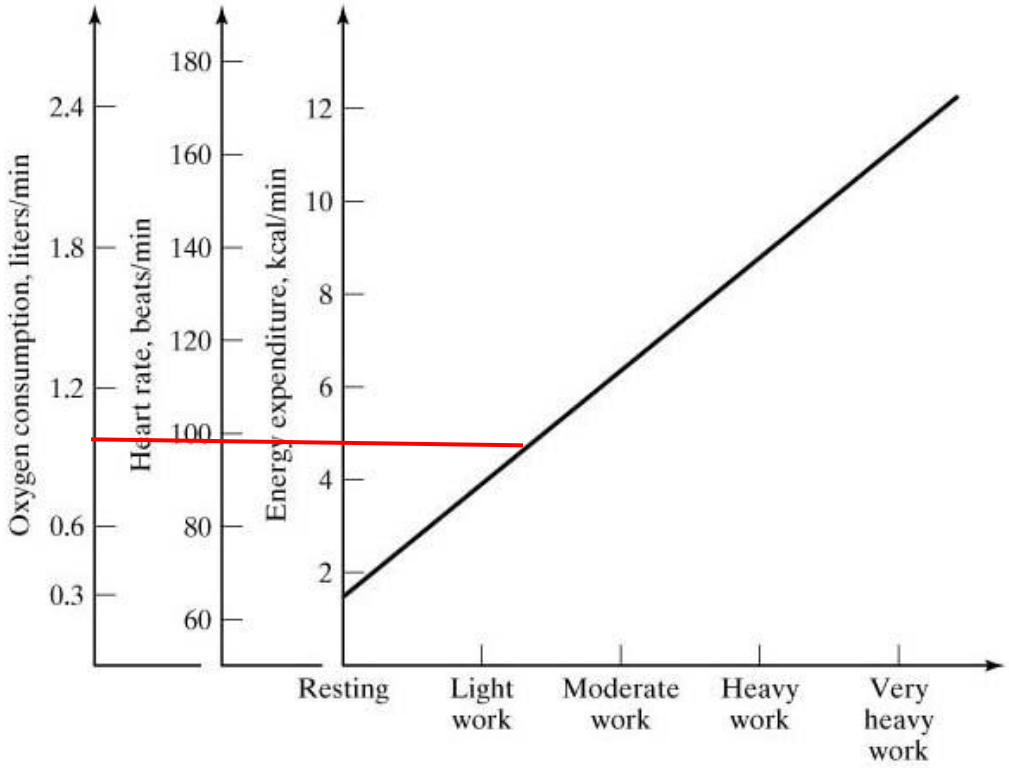
Work Activity and Energy Expenditure

Energy expenditure, heart rate, and oxygen consumption for several categories of work activity



Energy Expenditure Rates

- Every type of physical activity requires a certain energy expenditure: physiological cost of the activity to the body

- To perfrom these activities, the human must generate energy at a comparable rate in the form of basal and activity metabolism.

  - $ER_m = BMR_m + AMR_m$

  where

  ER_m = energy expenditure rate of the activity, kcal/min; $BMR_m + AMR_m$ = sum of basal and activity metabolic rates, kcal/min

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The daily total metabolic rate

= summation of energy expenditure rate * respective times during which they apply

+

Digestive metabolic rate

+

Basal metabolic rate while sleeping

- Table: is for a 72 kg-(160 lb) person
  - If the weight (W) differs from 72 kg
    - An adjustment by the ratio W/72.

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Energy Expenditure Rates

Sleeping	BMR_m
Standing (not walking)	2.2 kcal/min
Walking at 4.5 km/hr	4 kcal/min
Jogging at 7.2 km/hr	7.5 kcal/min
Soldering work (seated)	2.7 kcal/min
Mowing lawn (push mower)	8.3 kcal/min
Chopping wood	8 kcal/min
Shoveling in front of furnace	10 kcal/min

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Example: Total Daily Metabolic Rate

Given: 35-year old woman who weights 59 kg (130 lb)

- Sleeps 8 hours
- Walks to and from work for 1 hour at 4.5 km/hr
- Stands for 2 hours
- Performs soldering work for 6 hours while seated
- Watches TV and rests for 7 hr

- Determine her total metabolic rate for 24-hour period

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Total Metabolic Rate – TMR

Activity	Time	ER	Weight factor	Total energy
Sleeping	480 min	0.86 kcal/min	(no correction)	413 kcal
Walking	60 min	4.0 kcal/min	130/160 = 0.81	194 kcal
Standing	120 min	2.2 kcal/min	130/160 = 0.81	214 kcal
Soldering work	360 min	2.7 kcal/min	130/160 = 0.81	787 kcal
Other activities	420 min	1.5 kcal/min	130/160 = 0.81	510 kcal
	1440 min		$BMR_d + AMR_d =$	2,118 kcal
Digestive metabolism			$0.10(BMR_d + AMR_d) =$	212 kcal
			$TMR_d =$	2,330 kcal

Oxygen Debt

- Difference between amount of oxygen needed by muscles during physical activity and amount of oxygen supplied
  - Occurs at start of physical activity after body has been at rest
  - There is a time lag before the body can respond to increased need for oxygen
  - Glycolysis is anaerobic during this time lag
  - Oxygen debt must be repaid, so when activity stops, breathing and heart rate continue at high levels

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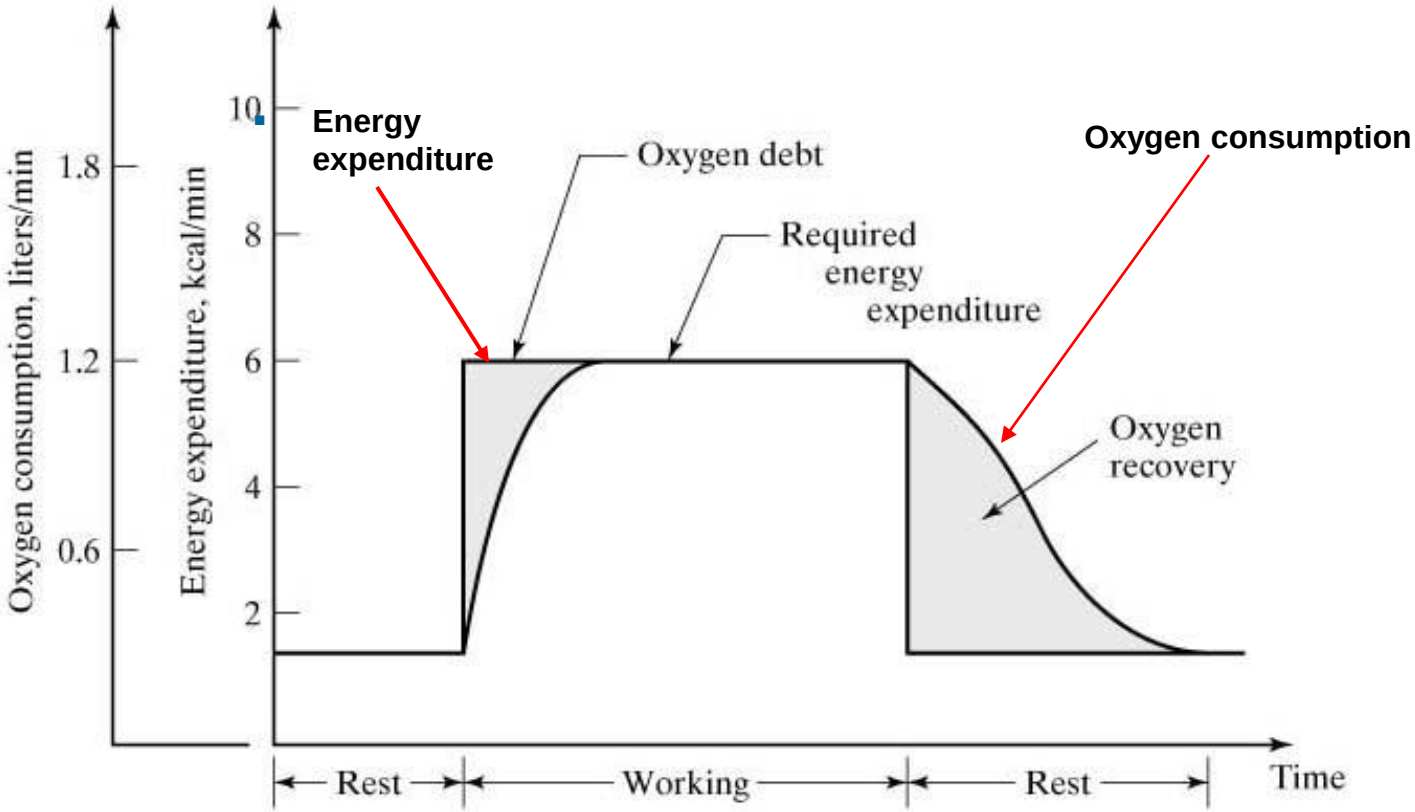
Oxygen Debt Illustrated



Recommended Energy Expenditure

Time weighted averages for individuals in good physical conditions

Physiological measure	Male worker	Female worker
Energy expenditure rate of the physical activity (maximum time-weighted average during shift) $\overline{ER}_m$	5.0 kcal/min	4.0 kcal/min
Energy expenditure of the physical activity for the entire 8 hr shift ER_{8h}	2400 kcal	1920 kcal
Heart rate (maximum time-weighted average during shift) $\overline{HR}_m$	120 beats/min	110 beats/min

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Time-weighted average energy expenditure

$$\overline{ER} = \frac{\sum_i T_i (ER_i)}{\sum_i T_i}$$

where $\overline{ER}$ = time-weighted average energy expenditure rate, kcal/min ; T_i=duration of time period i during total time period of interest, min; ER_i=energy expenditure rate during time period i

Example: Calculation of Time-Weighted Average of Energy Expenditure Rates

Given: A male worker performs a repetitive task that requires an energy expenditure rate of 7.5 kcal/min for 4.0 hours. Each hour, he works 40 min.s and takes a 20-min rest break. During the rest breaks, his energy expenditure rate is estimated to be 1.5 kcal/min.

Determine: The time-weighted average energy expenditure.

Solution:

$$\overline{ER} = \frac{40(7.5) + 20(1.5)}{60} = 5.5 \text{ kcal /min}$$

Exceeds the recommended value!

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Rest Periods

- Common in industry
  - Paid for by the employer as regular work time
  - Rest breaks usually included in allowance factor built into the time standard

    $T_{std} = T_n (1+A_{pfd})$
  - Rest breaks of short durations - 5 to 20 minutes are appropriate when the energy expenditure rates are less than the recommended values
  - Meal periods - not included
  - To compensate high energy expenditure periods with low ones; to recover from muscle fatigue, increased heart rate and lactic acid buildup

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Determining the length of rest periods

$$T_{rst} = \frac{T_{wrk}(E_{wrk} - \overline{ER})}{\left(\overline{ER} - ER_{rst}\right)}$$

where

T_{rst}= rest time, min;

T_{wrk}=working time, min;

ER_{wrk}=energy expenditure rate associated with physical activity, kcal/min;

$\overline{ER} =$ time-weighted average (standard) energy expenditure rate, kcal/min ; E

R_{rst}= metabolic rate of worker while resting, kcal/min (slightly above basal metabolic rate)

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An alternative form (skip)

$$T_{rst} = \frac{TT(E_{wrk} - \overline{ER})}{\left(E_{wrk} - ER_{rst}\right)}$$

where TT=T_{rst} + T_{wrk}= total time that includes both work time and rest time, min

Example: Determining the Aprropriate Rest Period for a Given Work Time

Given: A male worker performs physical labor that has an energy expenditure rate of 8.2 kcal/min for 20 min.

Determine: An appropriate length of a rest break.

Solution:

$$T_{rst} = \frac{20(8.2-5.0)}{(5.0-1.5)} = 18.29 \text{ min}$$

OR [20*(8.2)+x(1.5)]/(20+x)=5 find x

Then x is found as 18.29

Example: Determining the appropriate rest proportion for an 8-hour shift

Given: The worker in the previous example working in an 8-hour shift.

Determine:

(a) How should the 8-hour shift be divided between work periods and rest breaks?

(b) is omitted

(c) is omitted

Solution:

(a) Rest proportion = (8.2 -5.0) / (8.2 - 1.5)=0.4776=47.76%

or simply rest proportion = 18.29/(18.29+20)=0.4776=47.76%

This leaves 52.24% of the shifts as working time. Of the 8-hour shift, rest time accounts for 0.4776(8.0)=3.821 and work time accounts for 4.179 hours

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Scheduling of the work-rest cycles

- No break during the shift, but reduced shift duration: the worker would experience extreme fatigue
- Shorter work-rest cycles: improve the body's capability to improve the physiological recovery
  - Heart rate and lactic acid buildup is less
  - Recovery occurs more quickly
- In stead of working 4.179 hour, then resting for the remaining 3.821 hour, working 2 min, then resting for the remaining 1.8 min could be better.
- But we should also consider scheduling demands
- Physical training may be required to increase the worker's stamina, and also short rest breaks are recommended.

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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

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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

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

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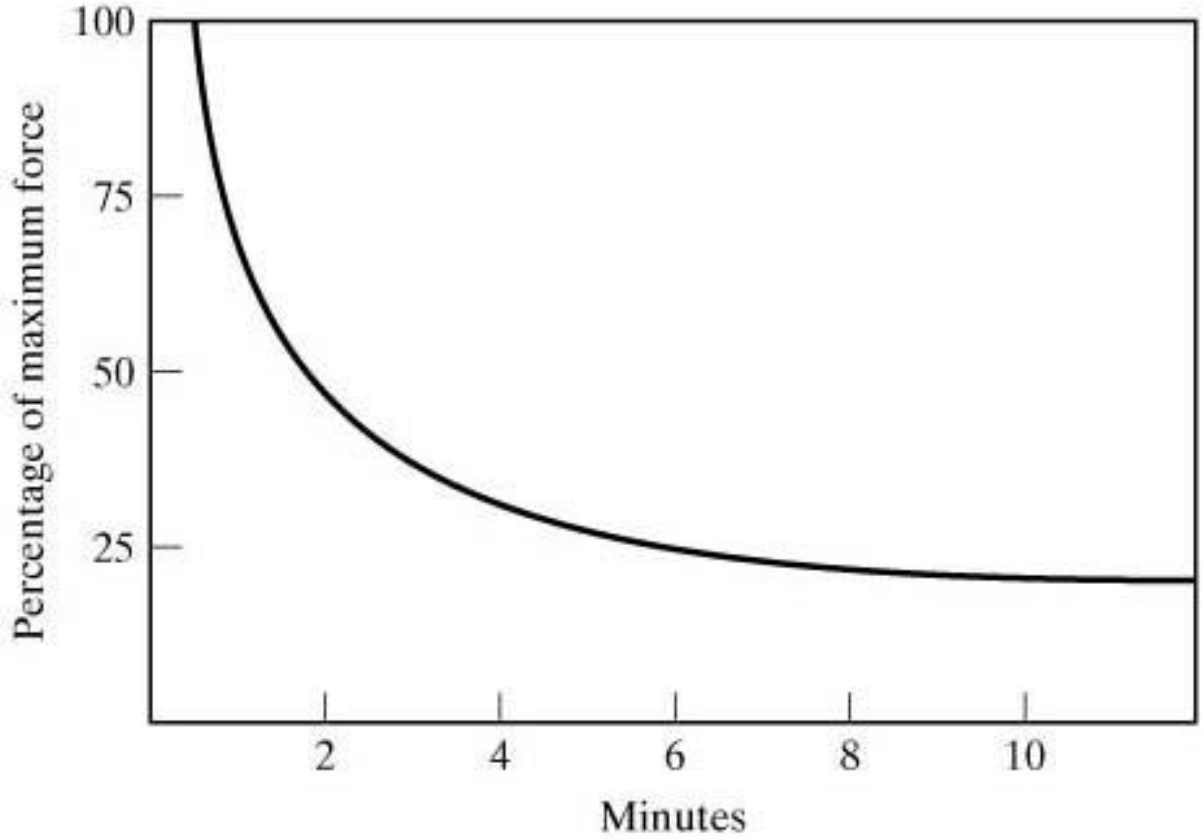
Muscle Endurance



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Dynamic Muscle Activity vs Static Force

- Dynamic muscle activity (requiring dynamic force application) in a repetitive motion cycle
-
  - 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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Importance in the design of work methods

- A worker cannot be expected to grip an object continuously at a high force level for an extended period of time
  - Use of a mechanical workholder rather than requiring worker to grasp work unit

- Dynamic muscular activity is physiologically better (less demanding) for the muscle cells than applying a static force, rotational motions rather than moves along straight lines

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Heat Balance and Thermoregulation

- Ability to maintain a proper thermal balance affects the capacity of human body to perform physical work (the third factor that affects human body in work).

- Normal body core temperature = 37°C (98.6 °F)

- Body core temperatures above or below this value mean trouble
  - Above 38°C (100°F), physiological performance is reduced
  - Above 40°C (104°F), body is disabled
  - Above 42°C (107°F), death likely

  Hypothermia
  - Below 35°C (95°F), coordination is reduced
  - Below 32°C (90°F), loss of consciousness likely
  - Below 30°C (86°F), severe cardiovascular stress

Body's Thermoregulation System

$$\Delta HC = M - W - E \pm R \pm C$$

where

- ΔHC = net change in heat content in the body
- M = metabolic energy produced
- W = work performed by the body
- E = heat lost through perspiration and evaporation
- R = radiant heat loss or gain
- C = heat loss or gain through convection

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Regulating Body Temperature

- Automatic body mechanisms
  - Sweating
  - Shivering
  - Constricting or dilating blood vessels
- Conscious actions
  - Clothing
  - Sun / shade
  - Exercising

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Anthropometry

- Empirical science concerned with the physical measurements of the human body, such as height, range of joint movements, and weight
- Derived from the Greek words anthropos (man) and metron (to measure)
- Usually considered a branch of anthropology
- Strength characteristics also sometimes included in the scope of anthropometry

Anthropometric Analysis and Data

1. Static dimensions – body measurements while in a fixed position
   - Data are more easily determined, so much more static data are available

2. Dynamic dimensions – body measurements while performing some physical activity
   - Probably more relevant in design

Human Variability

- Differences in body dimensions exist among people because of:
  - Ethnicity and Nationality
  - Heredity
  - Diet
  - Health
  - Sex
  - Age
  - Living conditions

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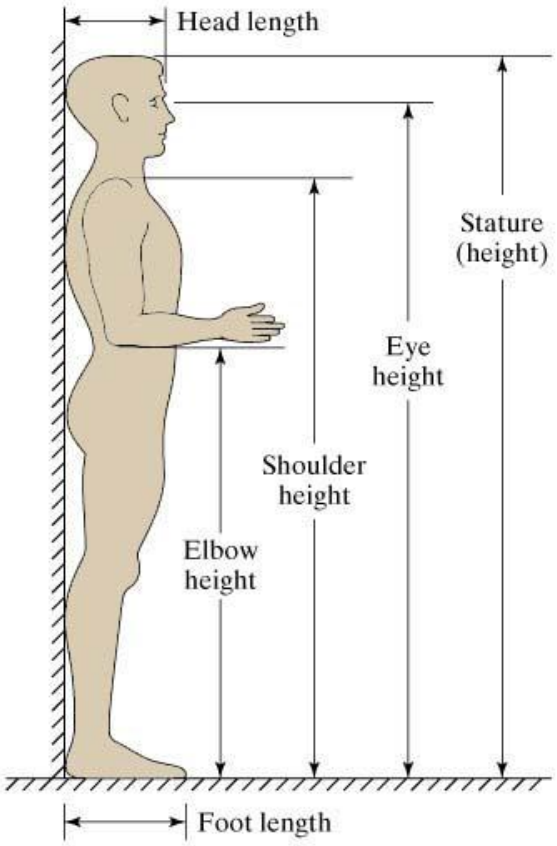
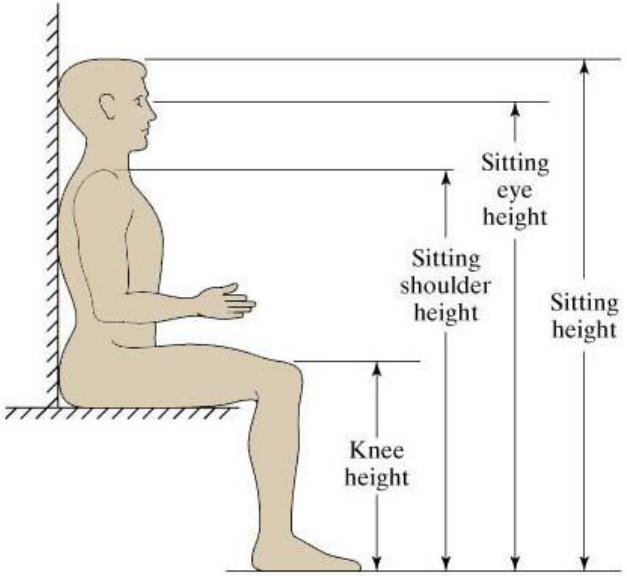
Static Dimensions of Human Body

Standing





Seated

Standing Heights of Males and Females throughout the World

	Males		Females	
Region	Centimeters	Inches	Centimeters	Inches
North America	179	70.5	165	65.0
Northern Europe	181	71.3	169	66.5
Central Europe	177	69.7	166	65.4
Southeastern Europe	173	68.1	162	63.8
India, North	167	65.7	154	60.6
India, South	162	63.8	150	59.1
Japan	172	67.7	159	62.6
Southeast Asia	163	64.2	153	60.2
Australia (European)	177	69.7	167	65.7
Africa, North	169	66.5	161	63.4
Africa, West	167	65.7	153	60.2

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Anthropometric Data

- Anthropometric data for a homogeneous population usually obeys normal distribution

- Published data indicate not only mean values but also some measure of dispersion
  - Percentile limits on the variable
    - 5th and 95th percentile points common
  - Standard deviation
    - Applies to specific anthropometric variable

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Normal Distribution in Anthropometry

Normal distribution for a given anthropometric variable of interest

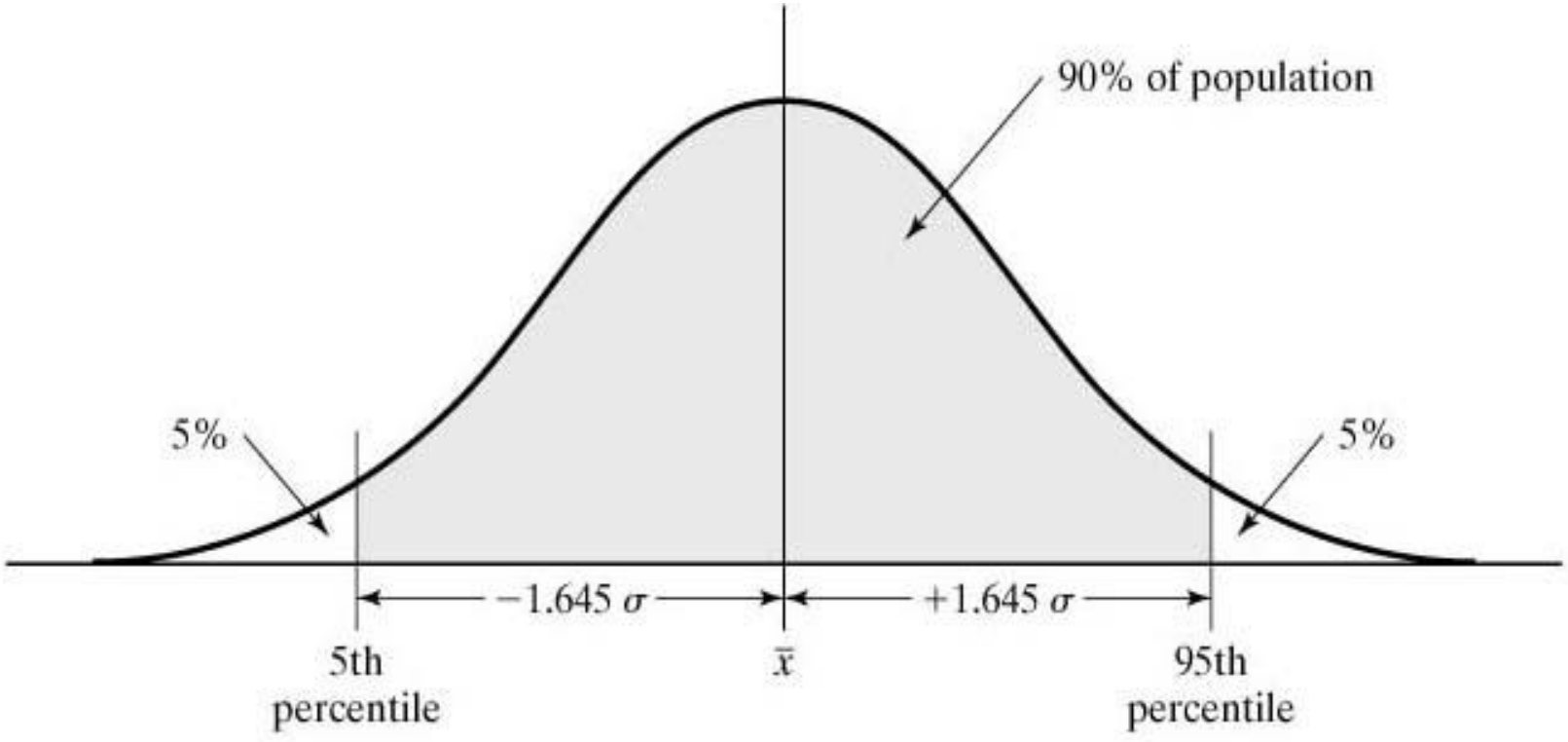

Table 15. Height in centimeters for females 20 years and over- number of examined persons, mean, standard error of the mean, and selected percentiles, by race-ethnicity and age : United States, 1988-1994

Race-ethnicity and age	Number of examined persons	Mean	Standard error of the mean	Selected percentile								
				5th	10th	15th	25th	50th	75th	85th	90th	95th
All race/ethnicity groups[1]												
20 years and over	9,067	161.8	0.15	150.4	153.1	154.9	157.2	161.7	166.4	169.1	170.8	173.1
20-29 years	1,867	162.7	0.26	151.7	154.5	155.7	158.0	162.6	167.7	170.2	171.7	174.3
30-39 years	1,863	163.4	0.26	152.1	154.7	156.3	158.8	163.5	168.2	170.4	172.2	174.9
40-49 years	1,371	162.8	0.28	152.0	154.9	156.6	158.6	162.6	167.1	169.6	170.9	172.9
50-59 years	1,009	161.8	0.32	151.5	154.0	155.6	157.5	162.1	166.1	168.4	170.3	172.2
60-69 years	1,177	160.2	0.30	150.0	152.3	154.1	156.1	160.1	164.7	166.5	168.5	171.2
70-79 years	988	158.0	0.34	147.2	149.8	152.1	154.0	158.2	162.6	164.8	166.1	167.9
80 years and over	792	154.9	0.39	143.8	146.2	148.2	150.9	155.1	159.4	161.8	163.5	165.7

Table 5. Weight in kilograms for males 20 years and over-number of examined persons, mean, standard error of the mean, and selected percentiles, by race-ethnicity and age : United States, 1988-1994

Race-ethnicity and age	Number of examined persons	Mean	Standard error of the mean	Selected percentile								
				5th	10th	15th	25th	50th	75th	85th	90th	95th
All race/ethnicity groups[1]												
20 years and over	7,942	82.1	0.38	59.7	63.7	66.1	70.9	80.0	90.6	97.5	102.8	110.8
20-29 years	1,630	78.3	0.62	57.7	60.9	63.1	67.1	75.0	85.3	93.2	99.1	107.7
30-39 years	1,481	83.0	0.68	61.8	64.6	67.4	72.0	79.9	91.3	98.8	102.9	112.7
40-49 years	1,226	85.1	0.76	61.5	66.0	68.6	74.4	82.2	93.9	101.6	105.7	116.6
50-59 years	855	86.0	0.80	63.4	68.2	72.0	75.7	84.1	94.0	100.7	105.3	114.3
60-69 years	1,175	83.1	0.65	61.1	64.5	67.7	72.8	82.4	92.5	98.4	102.0	107.3
70-79 years	875	79.0	0.71	58.5	62.0	64.2	68.8	77.9	87.0	93.5	96.1	103.3
80 years and over	700	71.8	0.74	52.0	56.2	58.4	63.6	70.8	78.7	84.1	88.0	93.1

Table 19. Sitting height in centimeters for females 20 years and over-number of examined persons, mean, standard error of the mean, and selected percentiles, by race-ethnicity and age : United States, 1988-1994

Race-ethnicity and age	Number of examined persons	Mean	Standard error of the mean	Selected percentile								
				5th	10th	15th	25th	50th	75th	85th	90th	95th
All race/ethnicity groups[1]												
20 years and over	8,598	85.5	0.09	78.8	80.5	81.6	83.0	85.6	88.1	89.5	90.4	91.7
20-29 years	1,837	86.1	0.13	80.2	81.5	82.5	83.6	86.1	88.5	90.0	90.9	92.0
30-39 years	1,837	86.7	0.13	80.6	82.0	82.9	84.4	86.6	89.1	90.3	91.3	92.5
40-49 years	1,338	86.5	0.15	80.8	82.1	82.9	84.1	86.6	88.9	90.1	90.9	92.5
50-59 years	981	85.5	0.17	79.5	80.8	82.1	83.4	85.6	88.0	89.1	89.8	91.1
60-69 years	1,107	84.0	0.15	78.6	79.9	80.9	82.0	84.0	86.2	87.4	88.4	89.5
70-79 years	894	82.4	0.20	76.0	77.6	78.7	80.2	82.8	84.9	86.2	86.8	88.0
80 years and over	604	79.6	0.24	72.9	74.5	75.6	77.1	79.6	82.4	83.6	84.6	85.8

Anthropometric Design Principles

- Design for extreme individuals
- Design for adjustability
- Design for the average user
- Design different sizes for different size users

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Design for Extreme Individuals

- Designing for the maximum (95th percentile)
  - Doorway heights
  - Automobile door openings
  - Mattress sizes

- Designing for the minimum (5th percentile)
  - Heights of kitchen cabinets
  - Locations of levers and dials on equipment
  - Weights of portable power tools

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Design for Adjustability

- To accommodate a wide range of users

- Examples:
  - Automobile driver seats
  - Adjustable steering wheel in an automobile
  - Office chairs
  - Worktable heights
  - Tilt angles of computer monitors
  - Lawnmower handle heights
  - Bicycle handlebars

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Design for Average User

- For situations in which design for extreme individuals and adjustability are not feasible
- Design for 50 th percentile
- Examples:
  - Stair heights
  - Stadium seats
  - Sofas
  - Heights of checkout counters at supermarkets
  - Lengths of shovel handles

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Different Sizes for Different Size Users

- When the only way to accommodate user population is to make the product in different sizes

- Examples:
  - Clothing
  - Shoes
  - Elementary school desks and chairs

Different Sizes for Different Size Users

Example: Men's suit coat sizes available from mail-order clothing store

Coat sizes	37	38	39	40	42	44	46	48	50	52	54	56	58	60
Short (under 5'8")	x	x	x	x	x	x								
Regular (5'8" to 5'11")	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Long (6' to 6'3")				x	x	x	x	x	x	x	x	x	x	x
Extra long (over 6'3")					x	x	x	x	x	x	x	x		
Portly short (under 5'8")					x	x	x	x						
Portly regular (5'8" to 5'11")					x	x	x	x	x	x				

Can you imagine the production and inventory problem for such a firm