

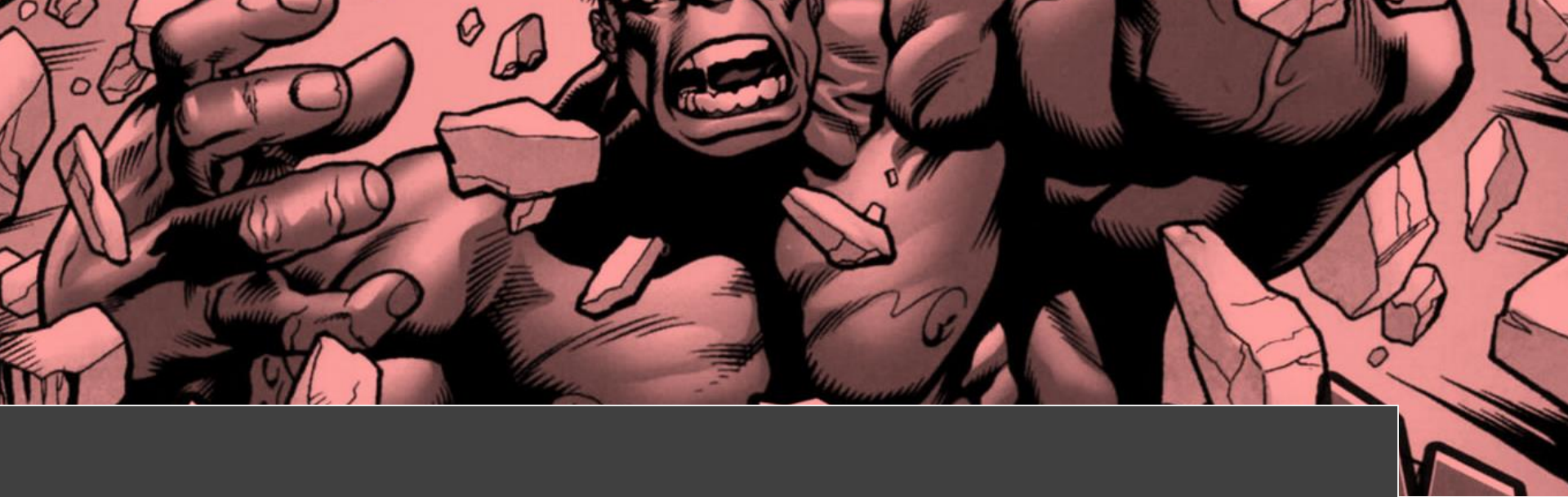


Chapter 8: Physical Work and Manual Materials Handlings

Human Factors in Engineering and Design

Mark S. Sanders and Ernest J.
McCormick

**RIDWAN AL AZIZ,
LECTURER, IPE, BUET**



Muscle Physiology

- Function of Muscles
- Type of Muscles
- Property of Muscles
- Structure of Muscles
- Growth of Muscles
- Terminologies

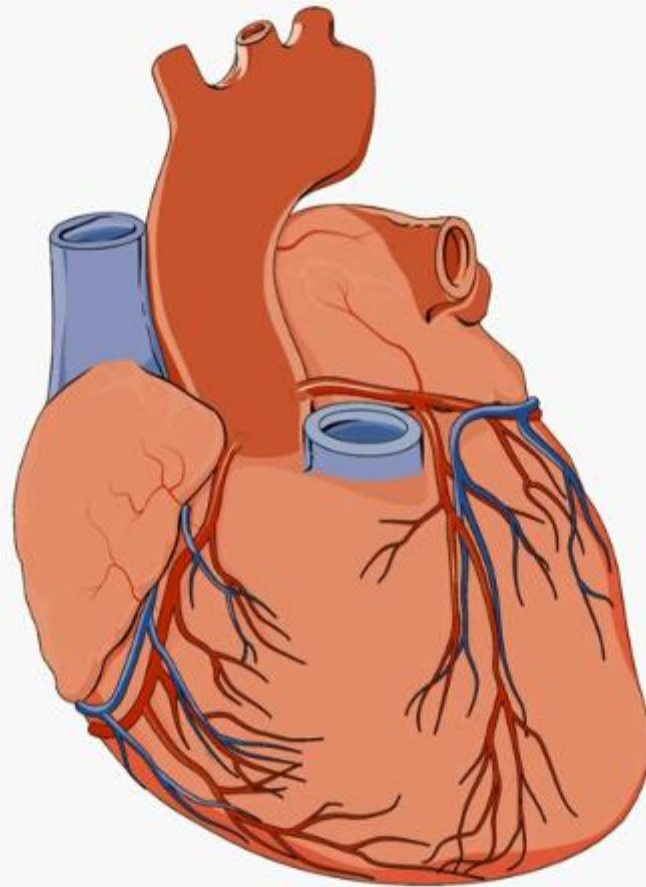
FUNCTION of MUSCLES



FUNCTION of MUSCLES



FUNCTION of MUSCLES



FUNCTION of MUSCLES



FUNCTION of MUSCLES



- ~40% of energy released in muscle activity useful as work
- Remaining energy (60%) given off as heat

FUNCTION of MUSCLES



Produce Body Movement



Stabilise Body Position



Store and Move Substances



Thermoregulation

TYPE of MUSCLES

Skeletal Muscle

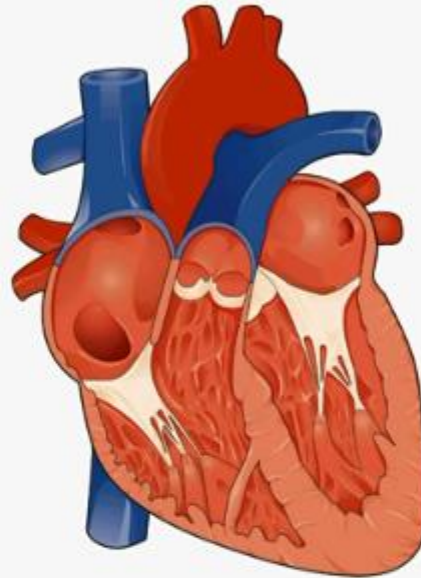


Tendon to Bone

Voluntary
(somatic nervous system)

Fast Contraction

Cardiac Muscle

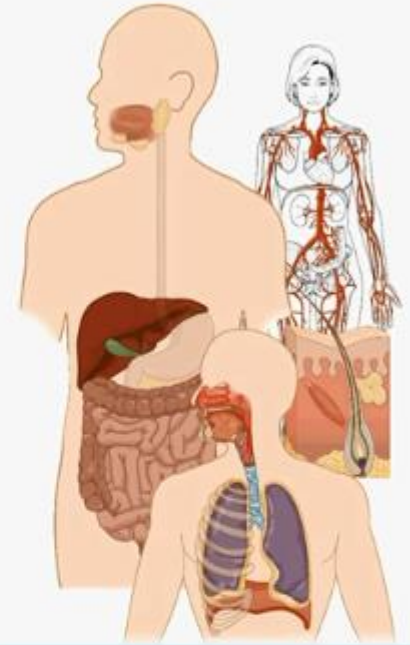


Heart

Involuntary
(autonomic nervous system)

Moderate Contraction

Smooth Muscle



Hollow Organs

Involuntary
(autonomic nervous system)

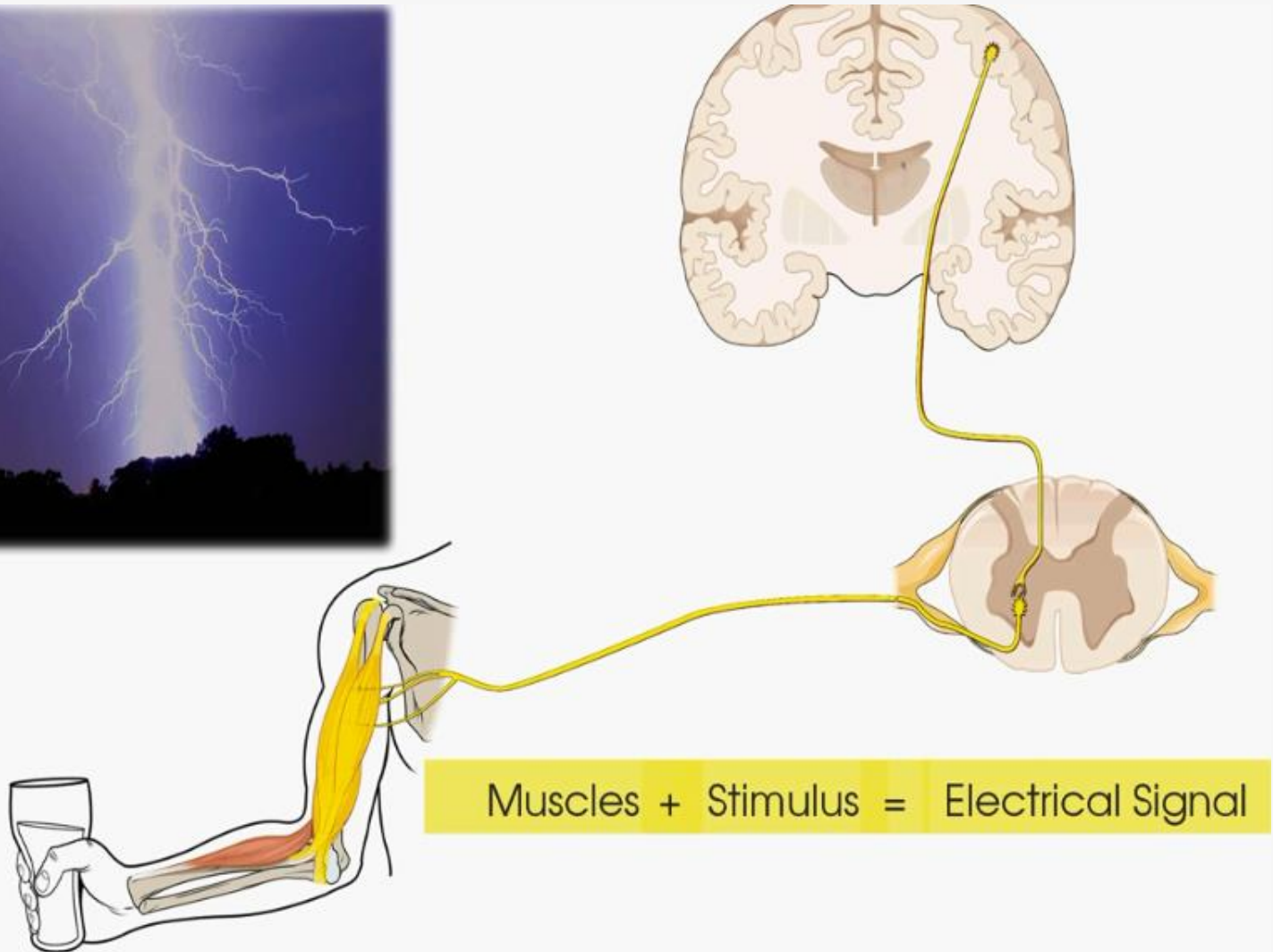
Slow Contraction

PROPERTY of MUSCLES



Electrical Excitability

PROPERTY of MUSCLES



PROPERTY of MUSCLES

Contractility



PROPERTY of MUSCLES

Extensibility



PROPERTY of MUSCLES

Elasticity



PROPERTY of MUSCLES



Electrical Excitability



Contractility



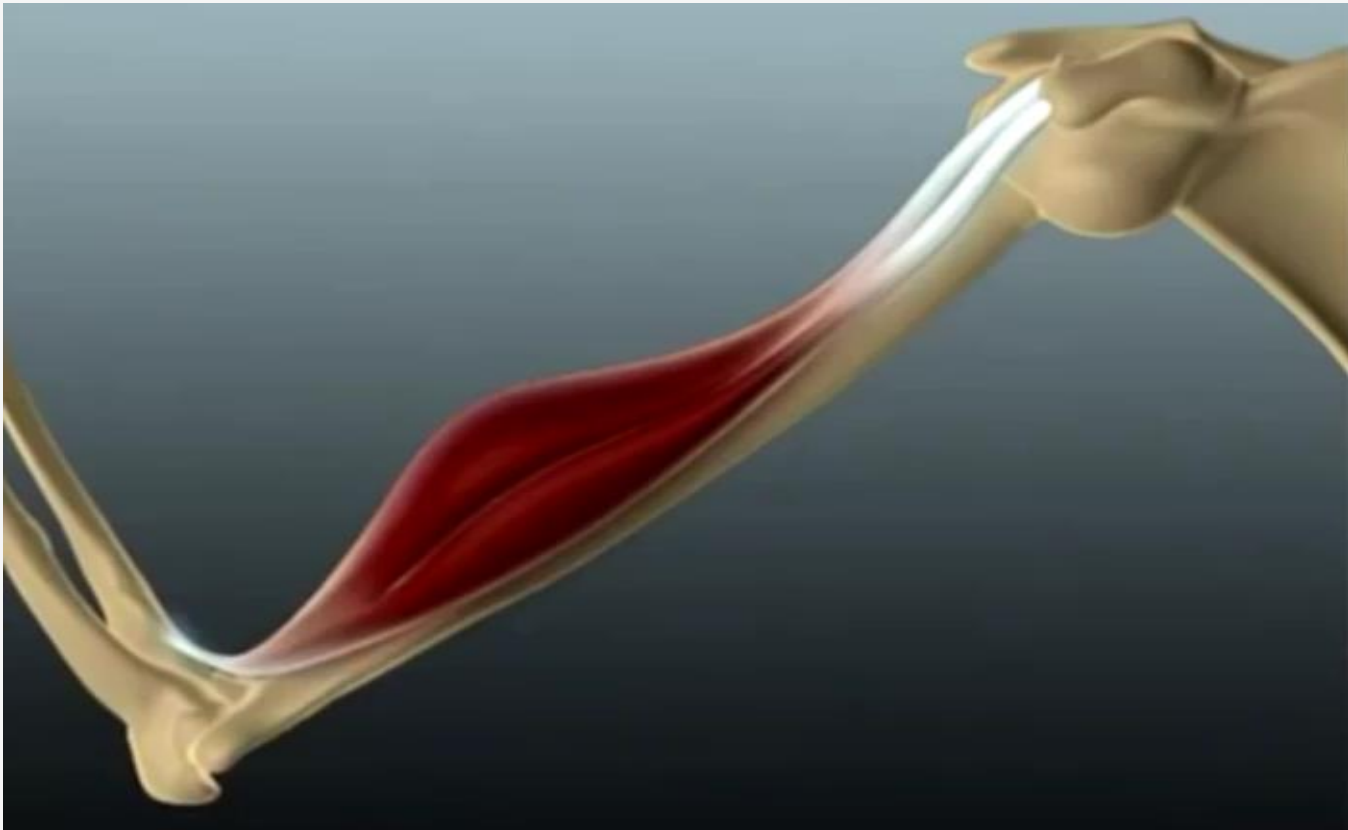
Extensibility



Elasticity

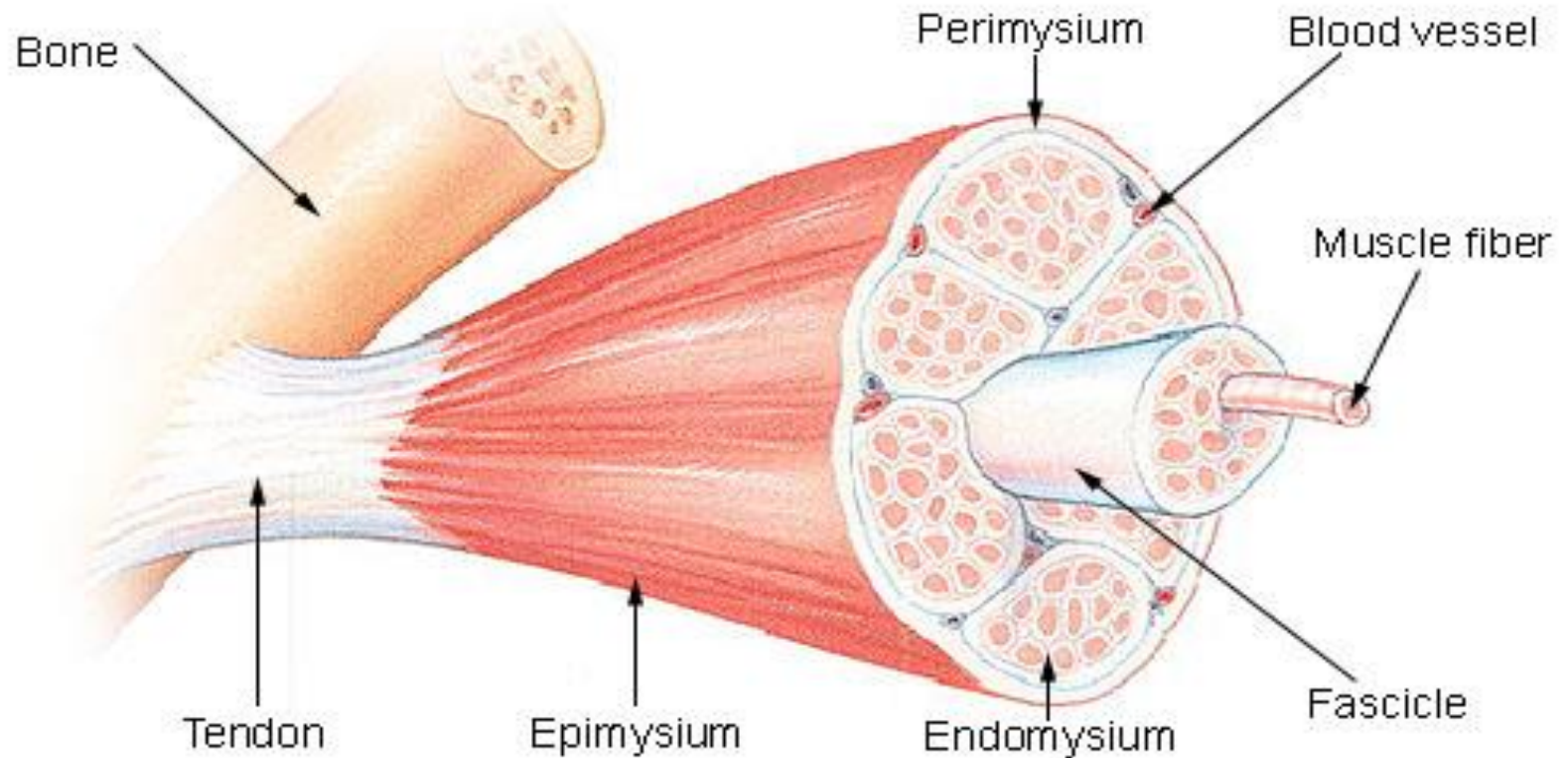
STRUCTURE of MUSCLES

- Focus on *skeletal muscles*
- 600 muscles in human body, over 400 are skeletal.
- Vigorous activities are carried out by fewer than 80 muscles.

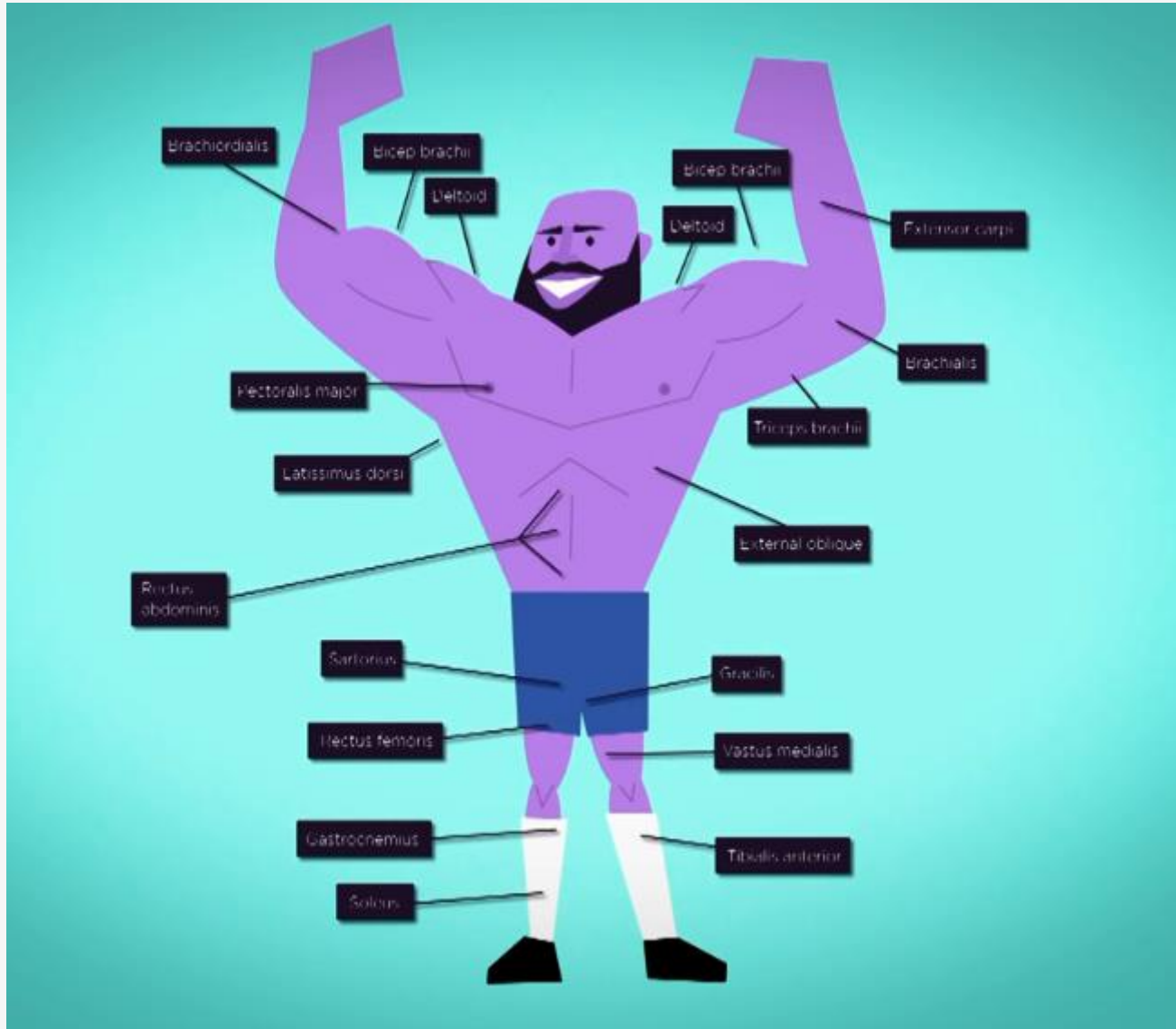


STRUCTURE of MUSCLES

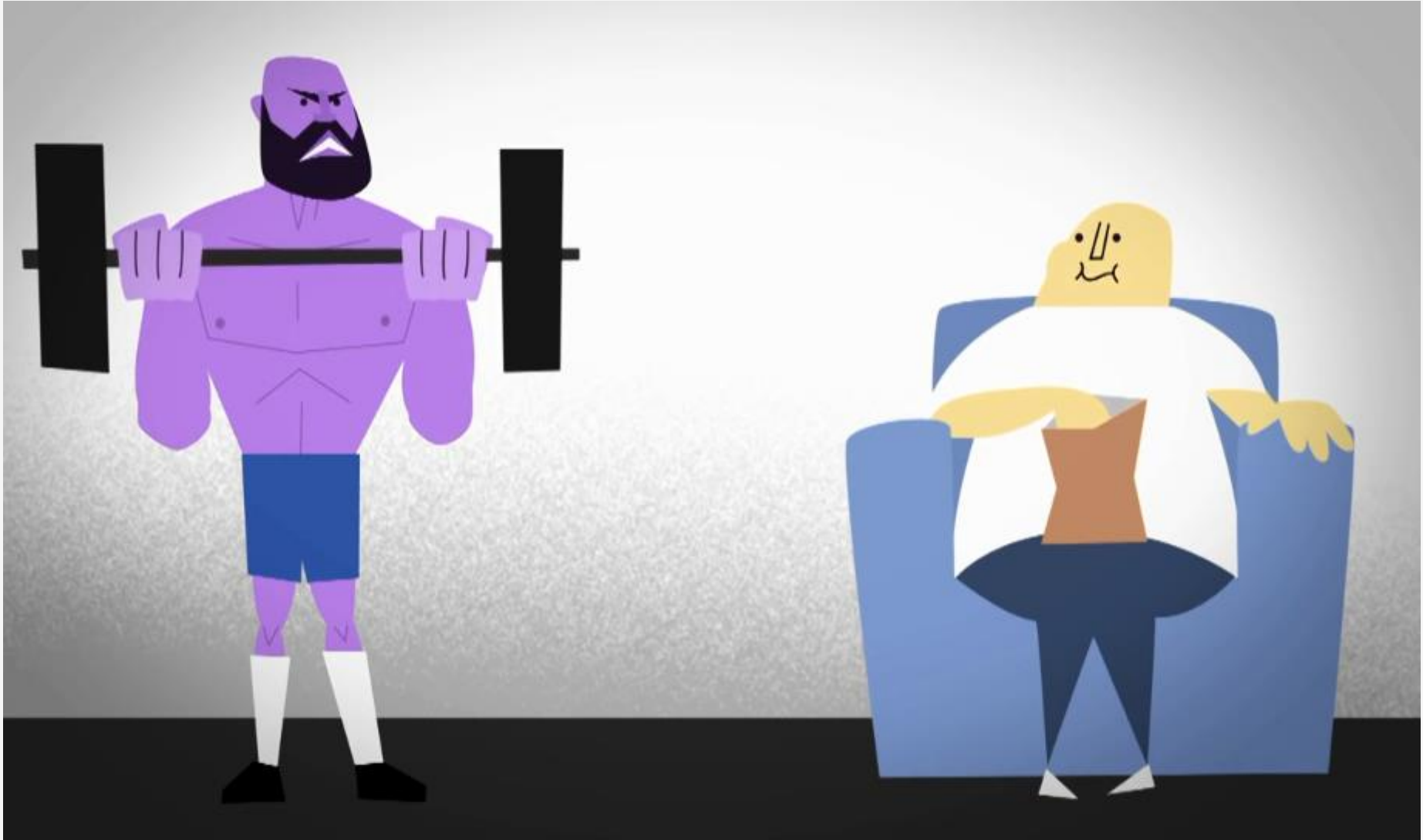
Structure of a Skeletal Muscle



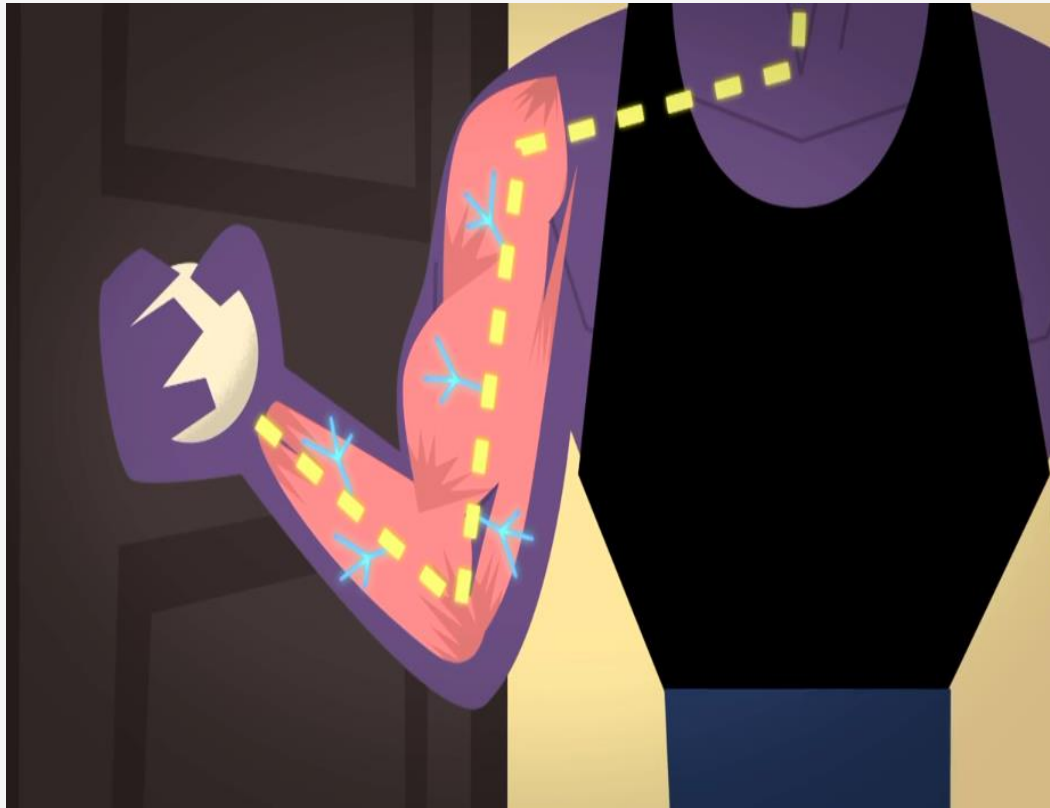
GROWTH of MUSCLES



GROWTH of MUSCLES



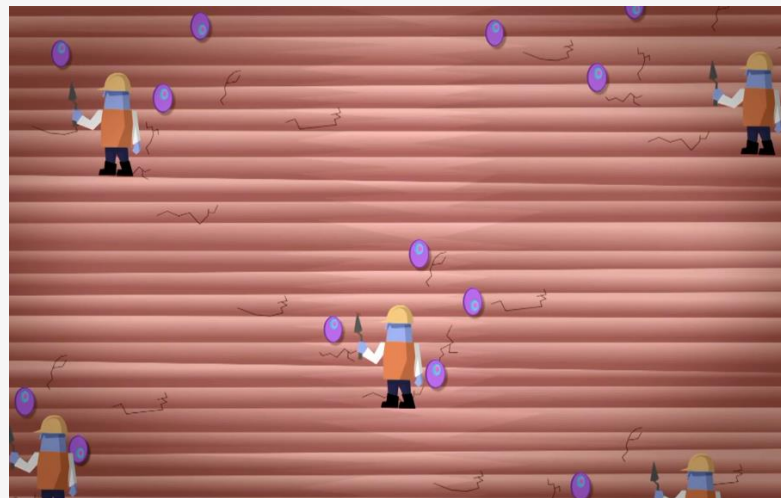
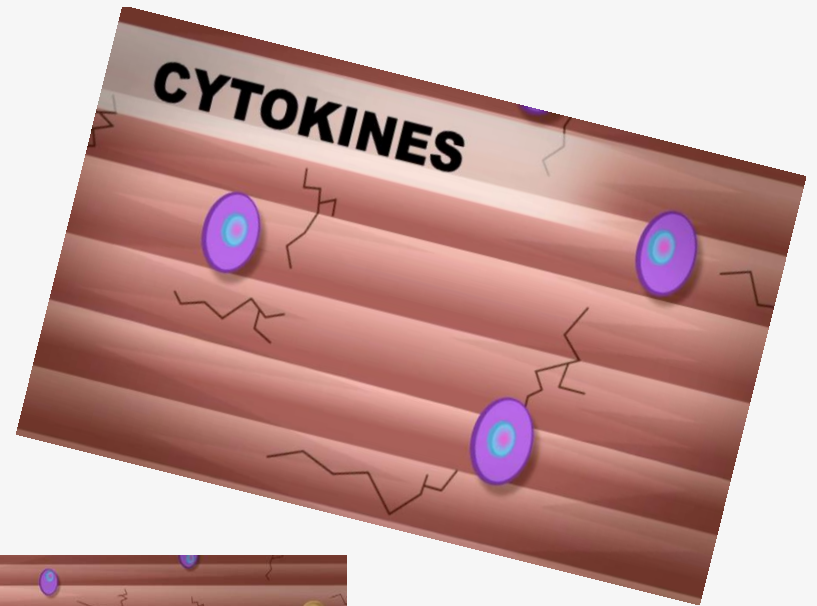
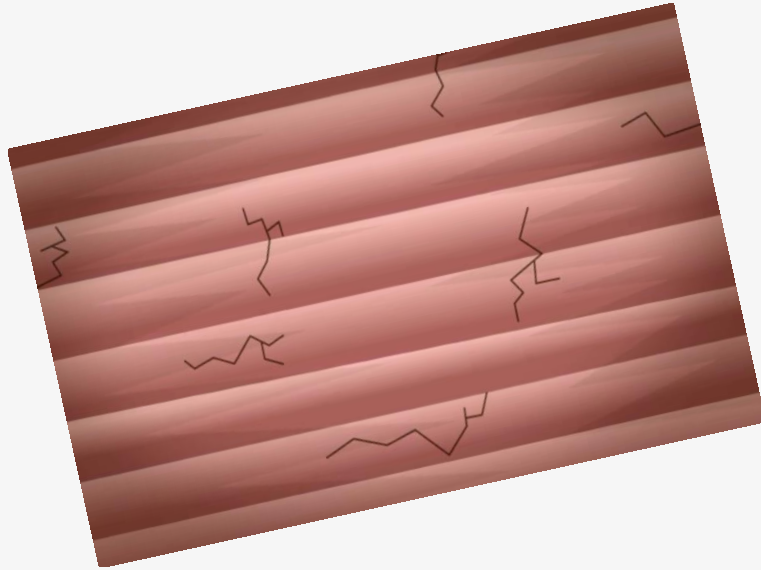
GROWTH of MUSCLES



GROWTH of MUSCLES



GROWTH of MUSCLES

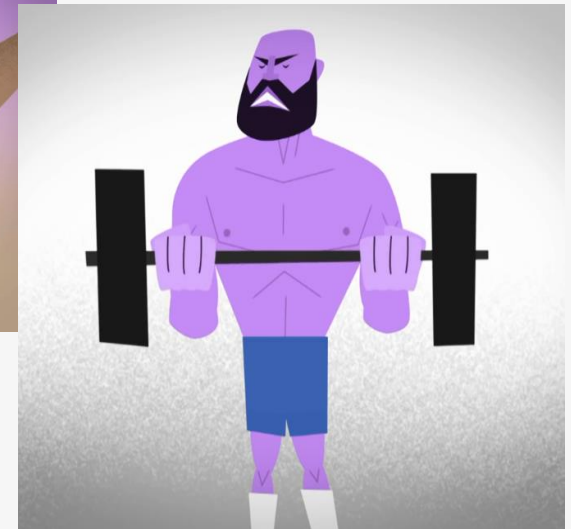
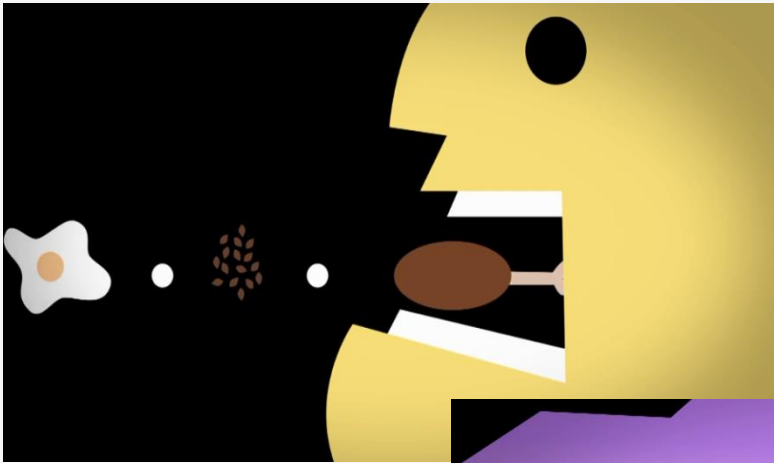


GROWTH of MUSCLES

**MUSCULAR
ATROPHY**



GROWTH of MUSCLES



RELATED TERMINOLOGIES

Oxygen debt

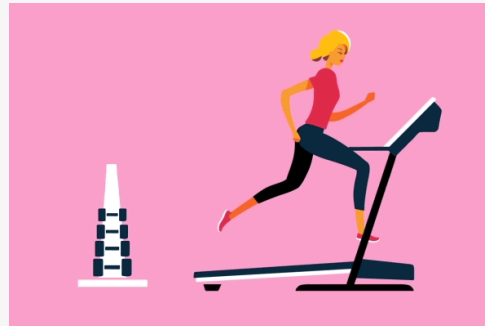
- Strenuous exercise uses up blood oxygen.
 - Heavy breathing after strenuous exercise.
 - Typically about 11 liters extra oxygen is consumed.
 - Purposes for extra oxygen:
 - » Replace oxygen reserves (myoglobin, blood hemoglobin, air in the lungs and dissolved in plasma).
 - » Replenish the creatine phosphate system.
 - » Convert lactic acid to glucose in kidneys and liver.
 - » Serve the elevated metabolic rate that occurs as long as the body temperature remains elevated by exercise.



RELATED TERMINOLOGIES

Endurance

- The ability to maintain high-intensity exercise for >5 minutes.
- Driven by 2 factors.
 1. Maximum oxygen uptake
 - Proportional to body size
 - Peaks at age 20
 - Larger in trained athletes and males
 2. Nutrient availability
 - Carbohydrate loading used by some athletes
 - » Packs glycogen into muscle cells



RELATED TERMINOLOGIES

Fatigue

- Inability of a muscle to maintain force of contraction after prolonged activity.
 - Insufficient Ca release, depletion of creatine phosphate, insufficient oxygen, depletion of glycogen, buildup of lactic acid.
 - Lactic acid inhibits cellular enzyme function.
 - Motor nerve fibers use up their acetylcholine.



Spasm

- A sudden involuntary contraction of a single muscle within a large group of muscles that is **usually painless**.

Cramp

- Involuntary and **often painful** muscle contractions.
 - Inadequate blood flow to muscles (such as in dehydration), overuse/injury, and abnormal blood electrolyte levels

RELATED TERMINOLOGIES

Basal Metabolic Rate

- ✿ Basal Metabolic Rate (BMR) is the rate of energy expended (to sustain life) by bodies when at rest.
- ✿ This is the minimum amount of energy needed by the organism to perform essential functions such as breathing, heartbeat and blood circulation, synthesis of molecules e.g. proteins, maintenance of ion gradients across membranes, etc.

RELATED TERMINOLOGIES

Basal Metabolic Rate

What is meant by "at rest" ?

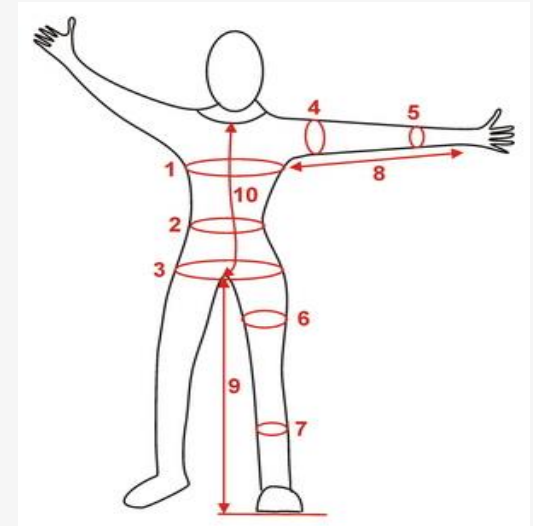
- ✓ When the subject (e.g. a person) is lying still, i.e. not making physical movements
- ✓ When the subject (e.g. a person) is quiet, i.e. not talking or otherwise under mental stress
- ✓ In a room that is comfortably warm - so that the body does not need to adjust body temperature
- ✓ Approx. 12-18 hours after the subject's most recent meal, so that energy is not being used for digestion and absorption of food (which can require significant energy).

RELATED TERMINOLOGIES

Basal Metabolic Rate

BMR depends on –

- ❖ Body size
- ❖ Age
- ❖ Gender





Work Physiology

- Respiratory Response
- Cardiovascular Response

RESPIRATORY RESPONSE

- **Increased rate of breathing and volume of air**

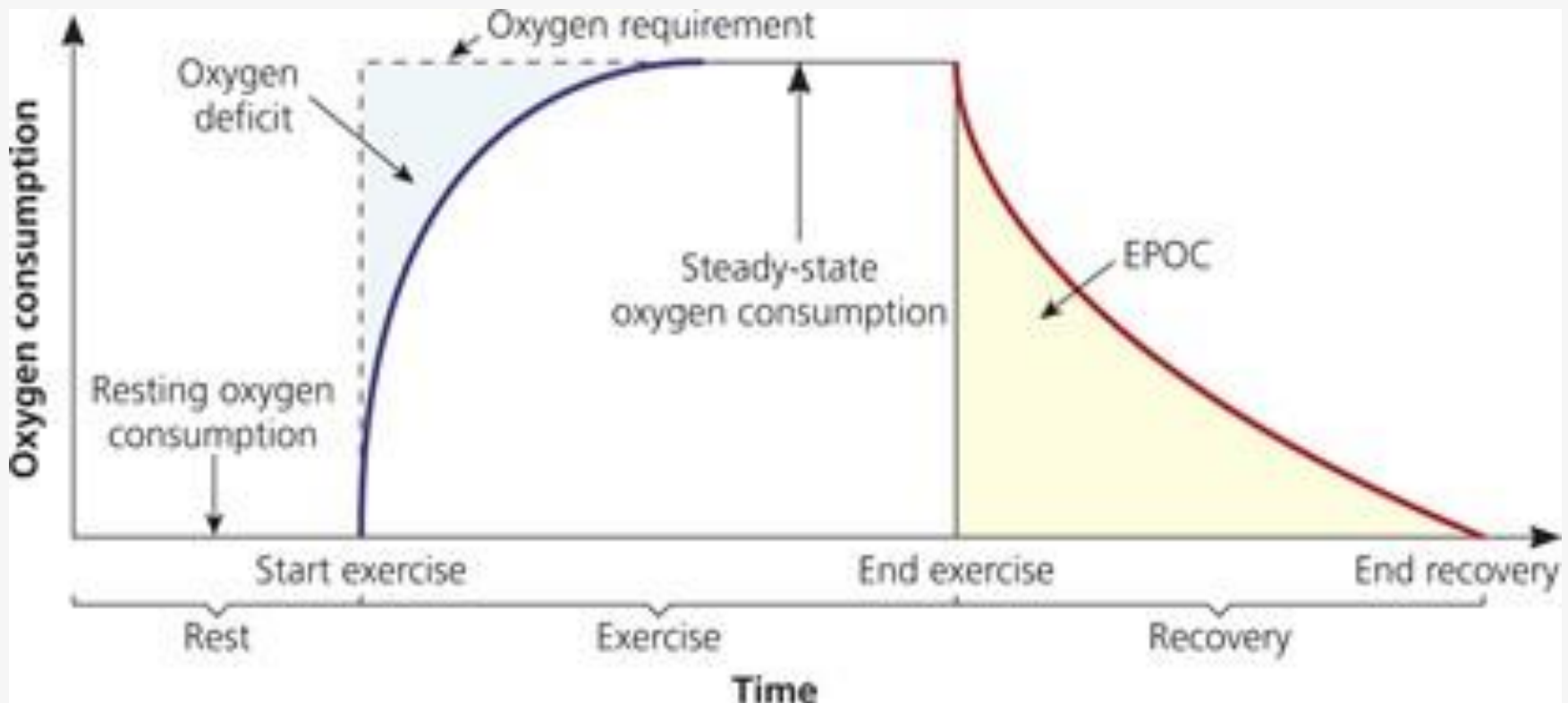


Rest : ***0.5 Liters*** of oxygen per minute

Heavy Work : ***5.0 Liters*** of oxygen per minute

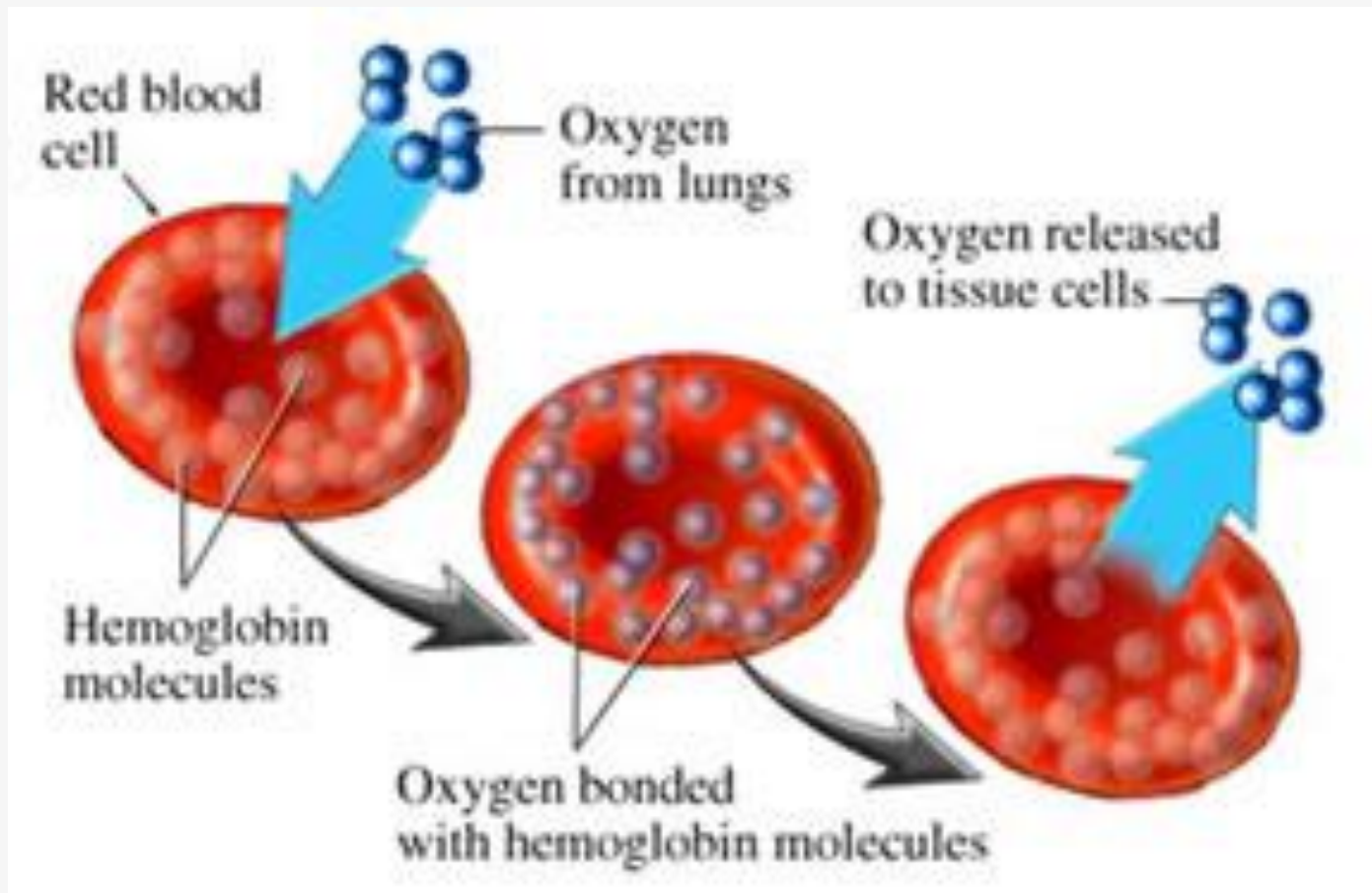
RESPIRATORY RESPONSE

- **Oxygen Debt/ Excess Post-exercise Oxygen Consumption (EPOC)**



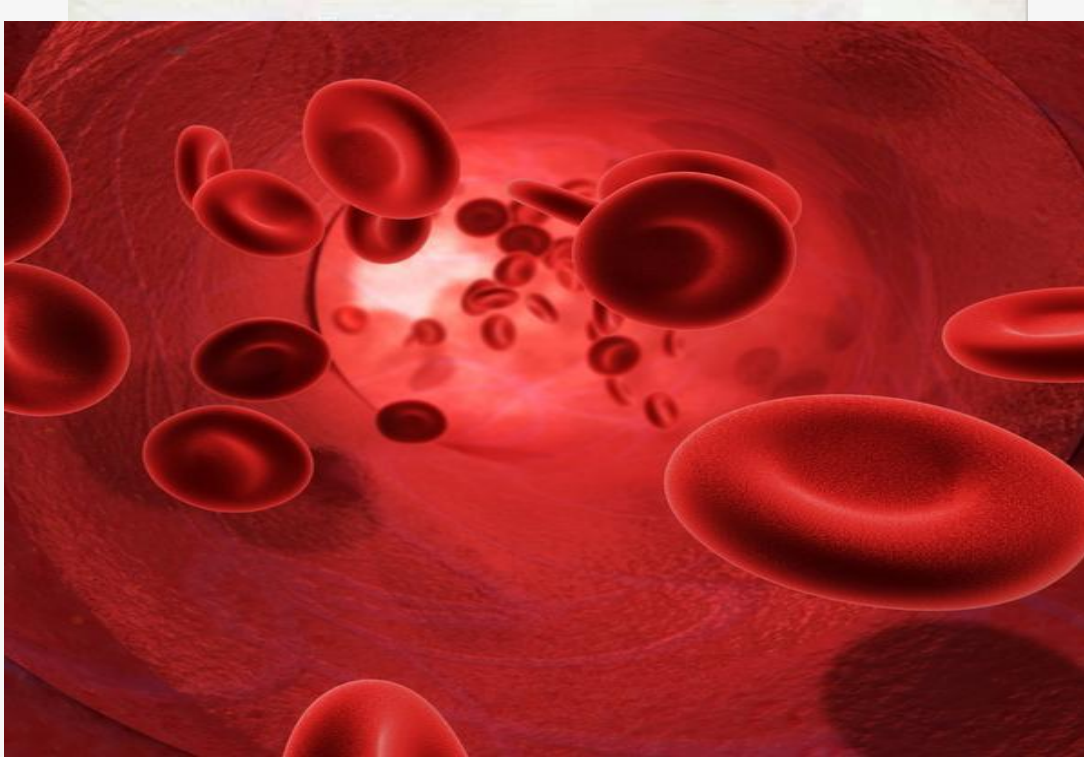
CARDIOVASCULAR RESPONSE

- **Increased Cardiac Output**



CARDIOVASCULAR RESPONSE

- **Increased Cardiac Output**



CARDIOVASCULAR RESPONSE

- **Increased Cardiac Output**

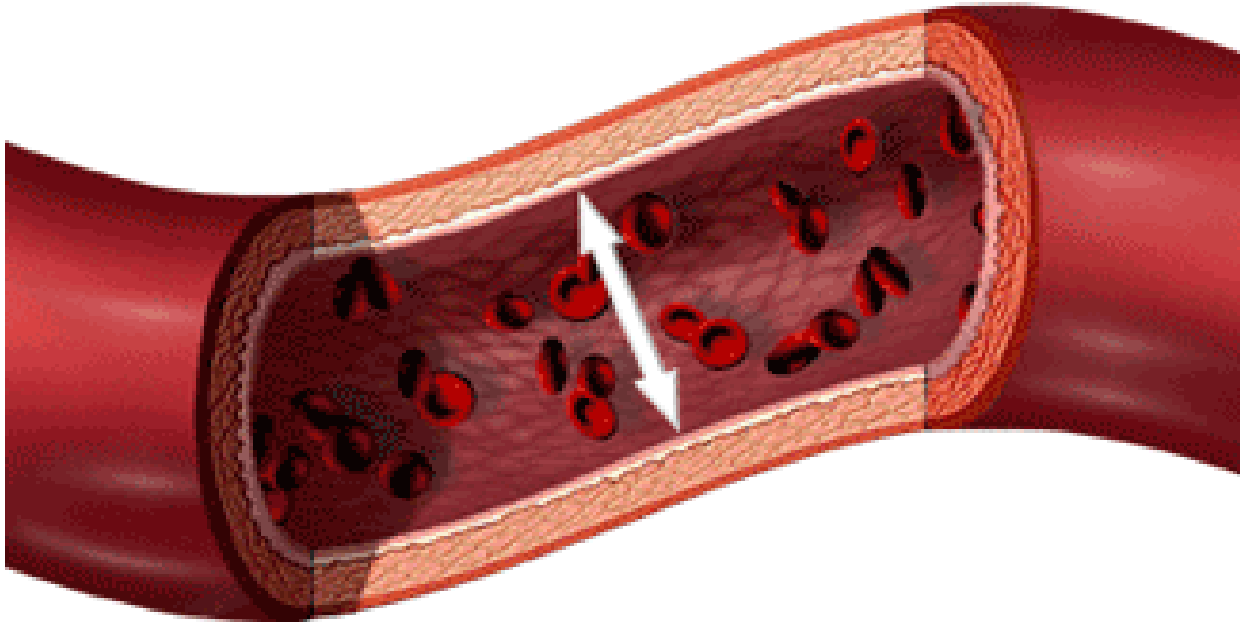
By 2 ways: Increasing heart rate
 Increasing stroke volume



CARDIOVASCULAR RESPONSE

- **Increased Blood Pressure**

Blood pressure is the measurement of force applied to artery walls



CARDIOVASCULAR RESPONSE

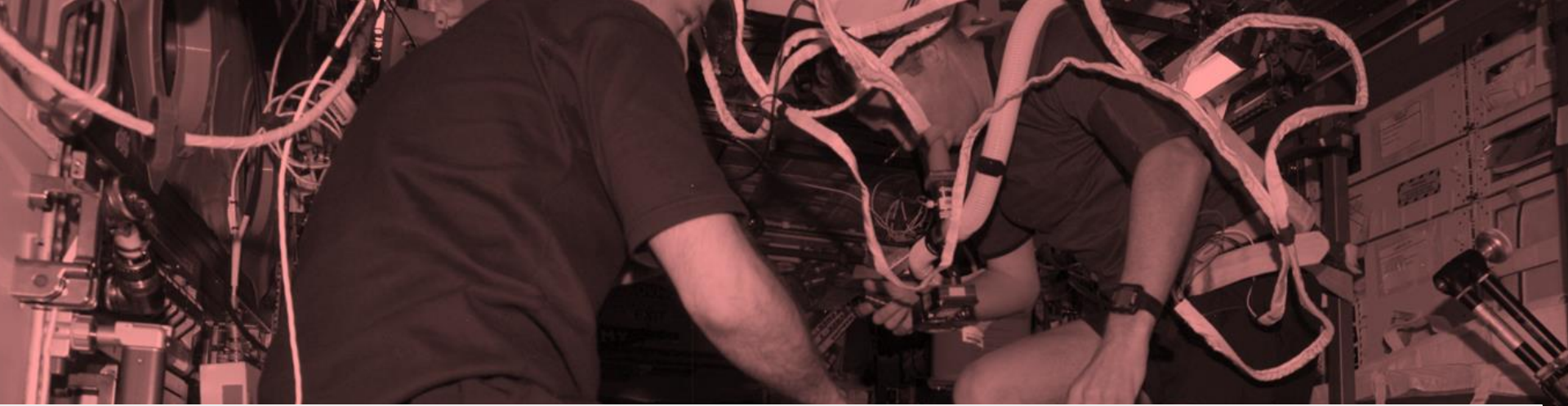
- **Redistribution of Blood Flow**

TABLE 8-1

DISTRIBUTION OF BLOOD DURING REST AND WORK SHOWN AS A PERCENTAGE OF CARDIAC OUTPUT

Part of body	Blood flow distribution (%)	
	Resting	Heavy work
Muscles	15-20	70-75
Skin	5	10
Brain	15	3-4
Bones	3-5	0.5-1
Kidneys	20	2-4
Digestive system	20-25	3-5
Heart muscle	4-5	4-5

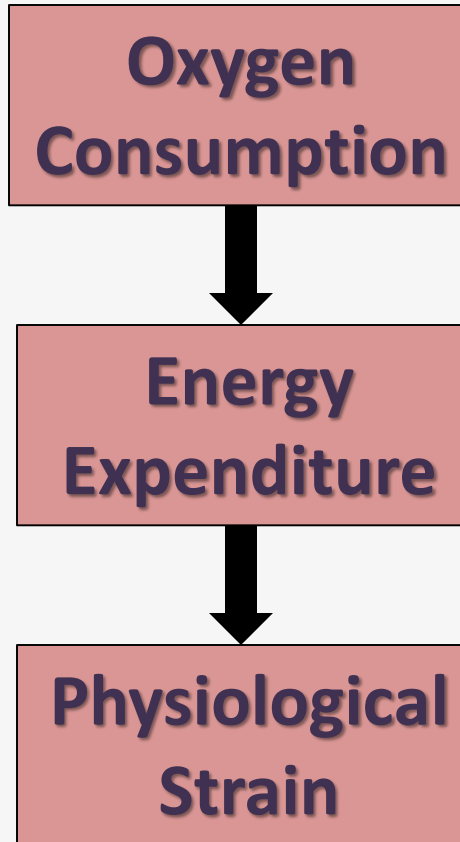
Source: Adapted from Astrand and Rodahl, 1986, Fig. 8-1. Reproduced with permission of McGraw-Hill.



Measure of Physiological Strain

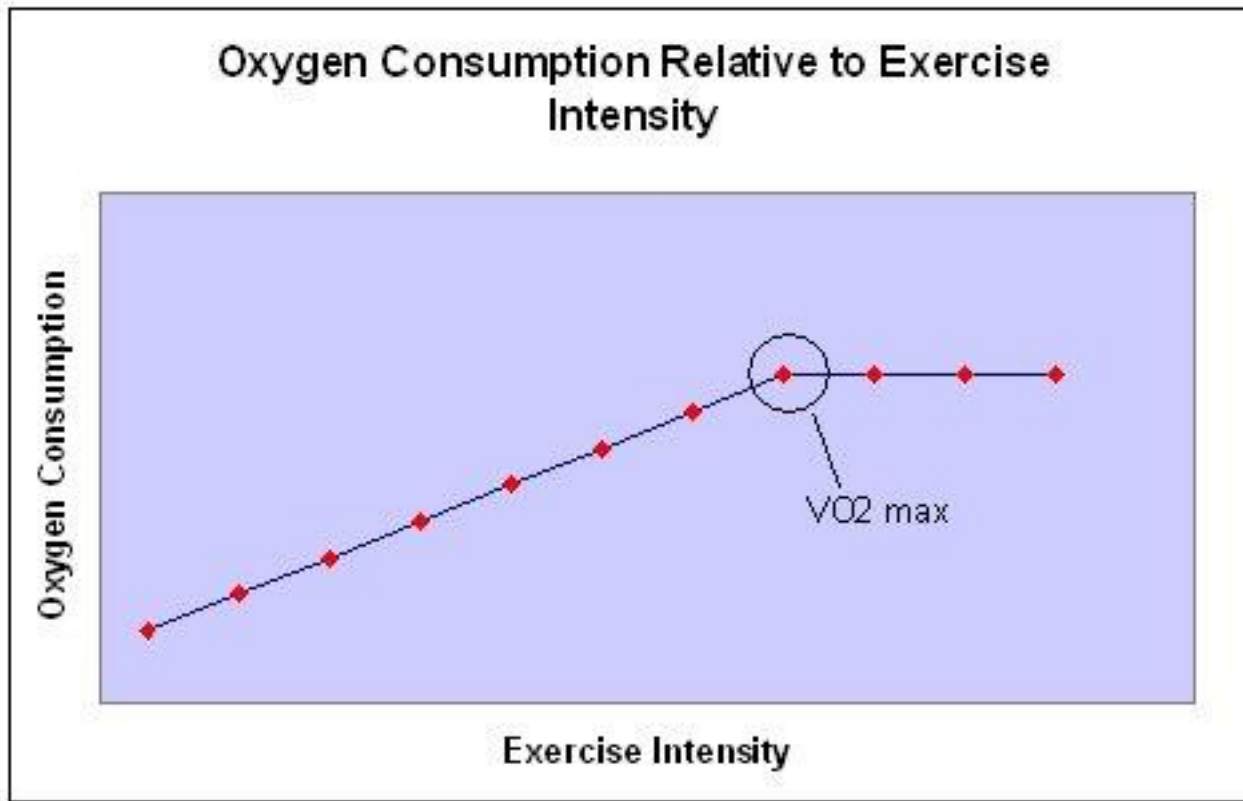
- Oxygen Consumption
- Heart Rate
- Hormone Secretion

OXYGEN CONSUMPTION



OXYGEN CONSUMPTION

Oxygen consumption linearly increases with rate of work.
Oxygen uptake eventually levels off. This is a person's
Maximum Aerobic Power (MAP)/ VO_2 Max.



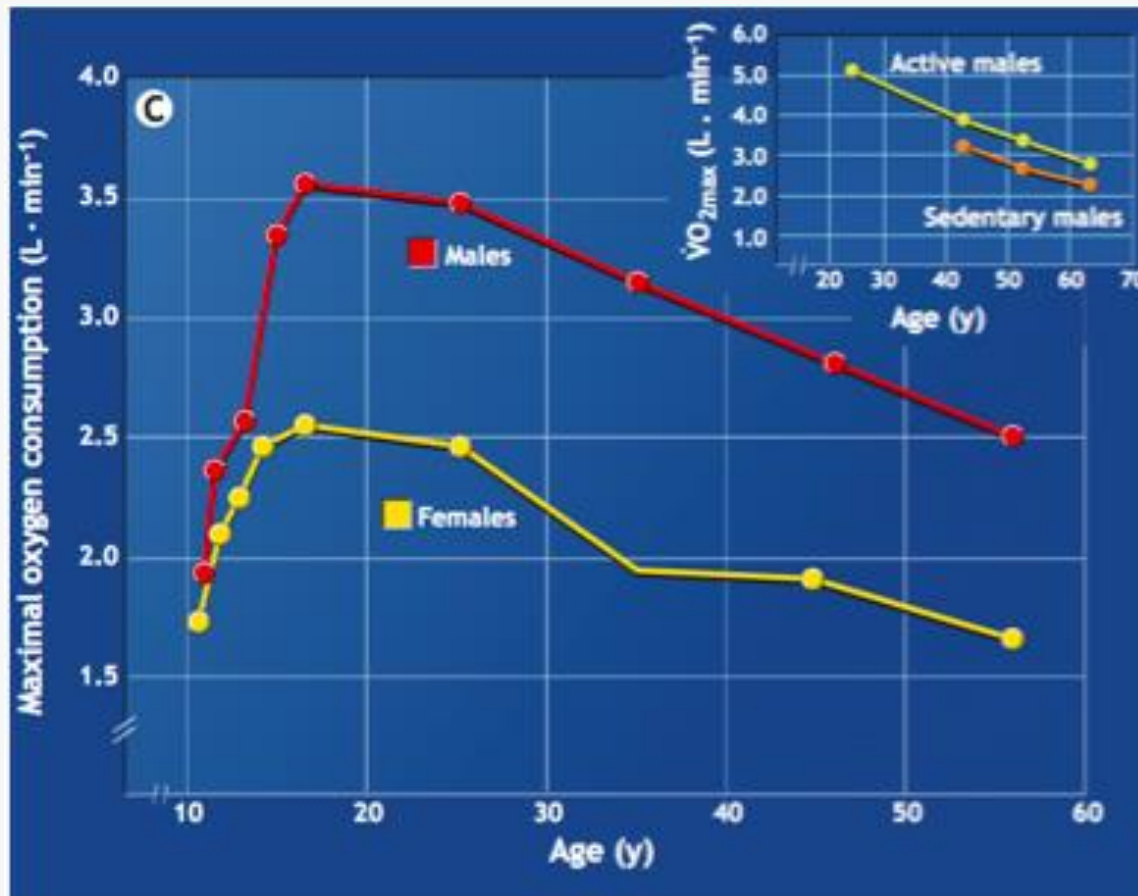
OXYGEN CONSUMPTION

To measure MAP of an individual, he has to exercise on a bicycle ergometer. The workload increases until the oxygen uptake levels off.



OXYGEN CONSUMPTION

Affect of Age and Sex on
Maximum Aerobic Power (MAP)/ VO₂ Max



HEART RATE

Oxygen consumption is hard to assess at the job. It is easier to measure heart rate. A few wires is attached to the person and a telemetry or recording device is all that needed.



HEART RATE

Problems with Heart Rate:

- ✓ Different relationship between different people.
- ✓ Heart rate is best used as predictor of oxygen consumption when moderate to heavy work is performed.
- ✓ There are lots of other factors such as emotional, stress fatigue, heat stress that affect heart rate but not oxygen consumption.

HORMONE SECRETION

- Adrenal glands secrete hormones when the body is under stress both physical and mental. The principal hormones are epinephrine and norepinephrine.
- The level of these hormones can be in the blood or urine can be used as a measure of occupational stress.

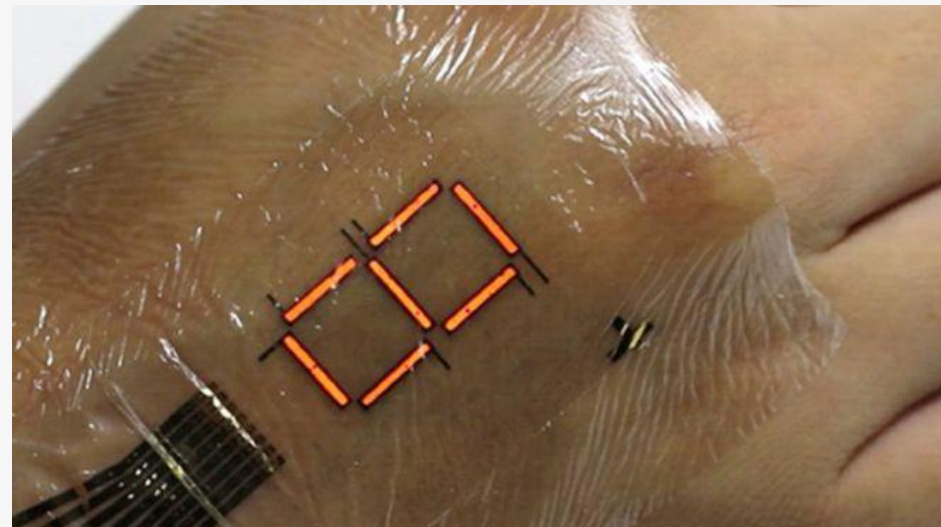
LATEST TECHNOLOGY

Scientists at the **University of Tokyo** in **Japan** have developed '**ultra-thin electronic skin**' that can measure oxygen levels when stuck to the body.

The goal is to monitor oxygen levels during surgery.

The device contains micro-electronic components that light up in red, blue and green on the surface of the body.

They are working on ways to display numbers and letters on the skin for health monitoring purposes.





Physical Workload

- Work Efficiency
- Grades of Work
- Factors Affecting Energy Consumption

WORK EFFICIENCY

- 60-70% of energy -> heat & unproductive static effort
- $Efficiency(\%) = \frac{work\ output}{energy\ consumption} * 100$
- Tools, posture, and activities affect work efficiency

WORK EFFICIENCY

TABLE 8-2
ESTIMATED WORK EFFICIENCY FOR VARIOUS
ACTIVITIES

Activity	Efficiency (%)
Shoveling (stooped posture)	3
Shoveling (normal posture)	6
Using heavy hammer	15
Going up and down stairs (no load)	23
Pulling a cart	24
Pushing a cart	27
Cycling	25
Walking on level (no load)	27

Source: Grandjean, 1988, Table 14.

WORK EFFICIENCY

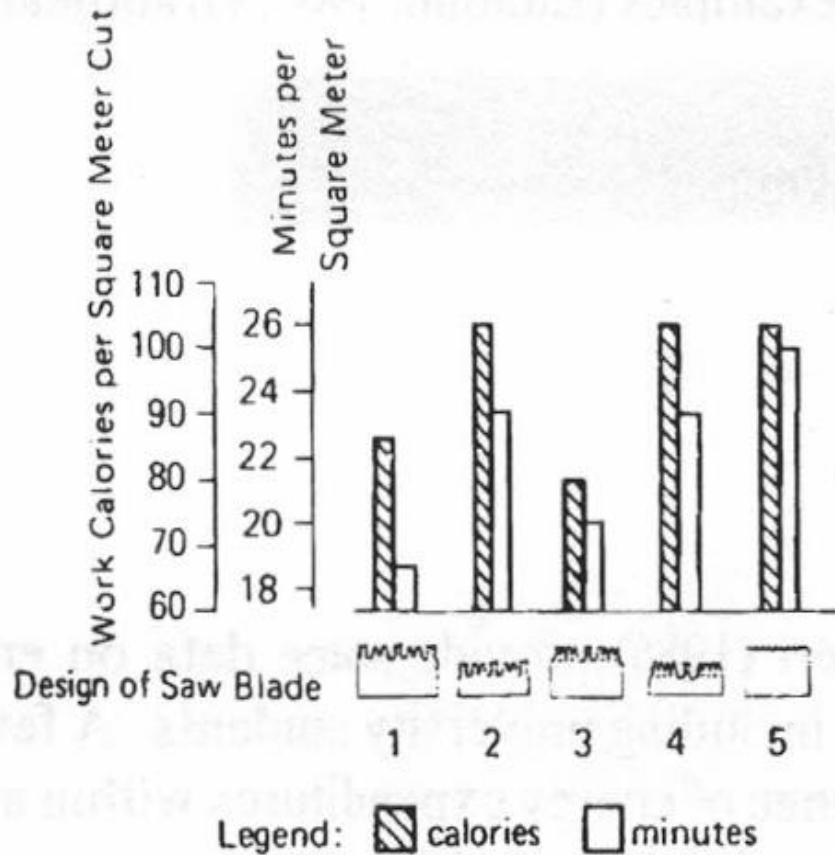


FIGURE 8-9

Calories expended and time spent in cutting a standard unit of work with five timber saws (unit of work: 1 m² of area cut). Saws 1 and 3 were clearly most efficient. (From Grandjean, 1988, Fig. 73, p. 89.)

GRADES OF WORK

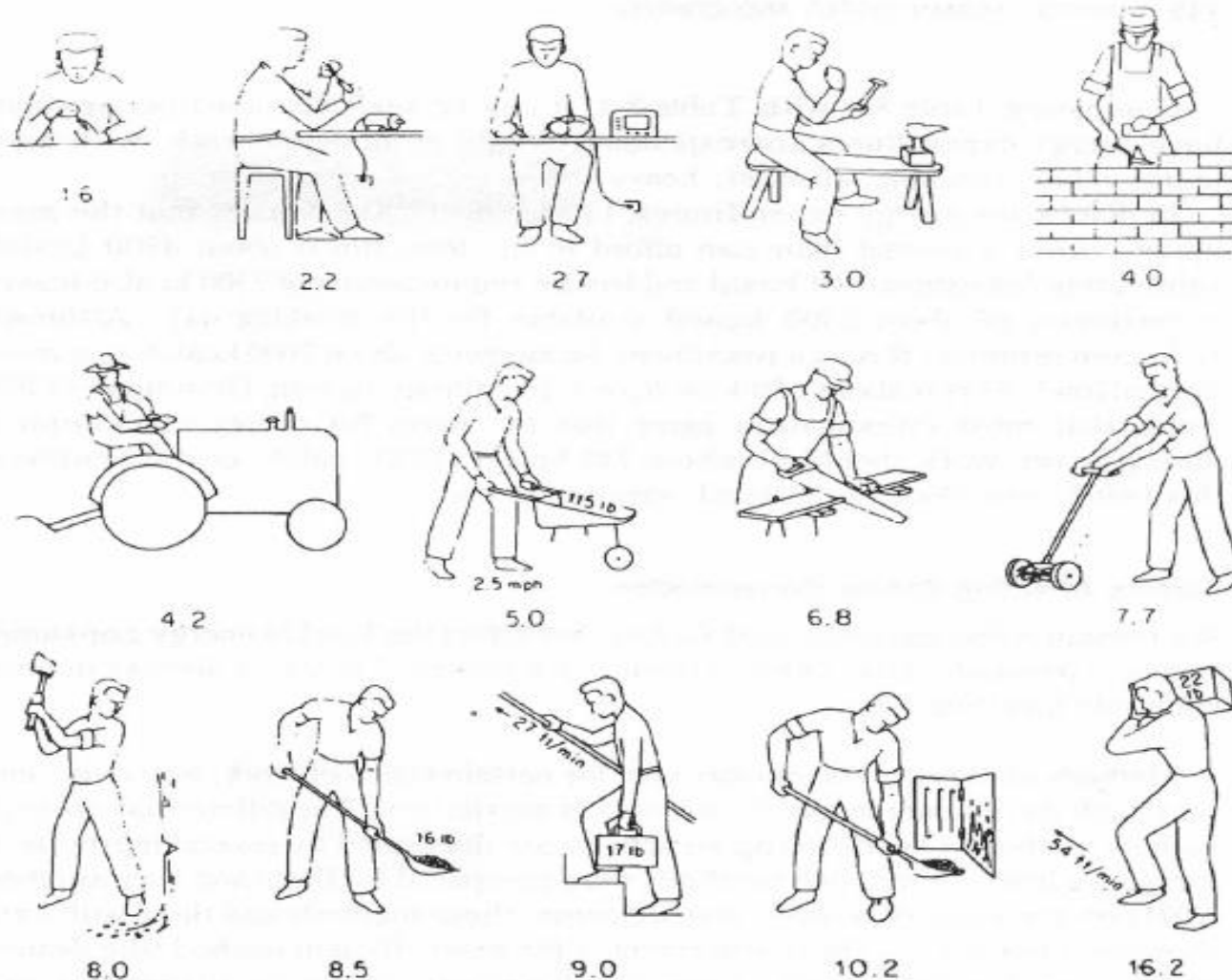


FIGURE 8-11

Examples of energy costs of various types of human activity. Energy costs are given in kilocalories per minute. (Source: *Passmore and Durnin, 1955, as adapted and presented by Gordon, 1957.*)

GRADES OF WORK

TABLE 8-4

GRADE OF PHYSICAL WORK BASED ON ENERGY EXPENDITURE LEVEL (ASSUMING A REASONABLY FIT ADULT MALE)

Grade of work	Energy expenditure, kcal/min	Energy expenditure, B h (kcal/d)	Heart rate, beats per minute	Oxygen consumption, L/min
Rest (sitting)	1.5	<720	60-70	0.3
Very light work	1.6-2.5	768-1200	65-75	0.3-0.5
Light work	2.5-5.0	1200-2400	75-100	0.5-1.0
Moderate work	5.0-7.5	2400-3600	100-125	1.0-1.5
Heavy work	7.5-10.0	3600-4800	125-150	1.5-2.0
Very heavy work	10.0-12.5	4800-6000	150-180	2.0-2.5
Unduly heavy work	>12.5	>6000	>180	>2.5

Source: Adapted from American Industrial Hygiene Association, 1971. Reprinted with permission by American Industrial Hygiene Association.

FACTORS AFFECTING ENERGY CONSUMPTION: Methods of Work

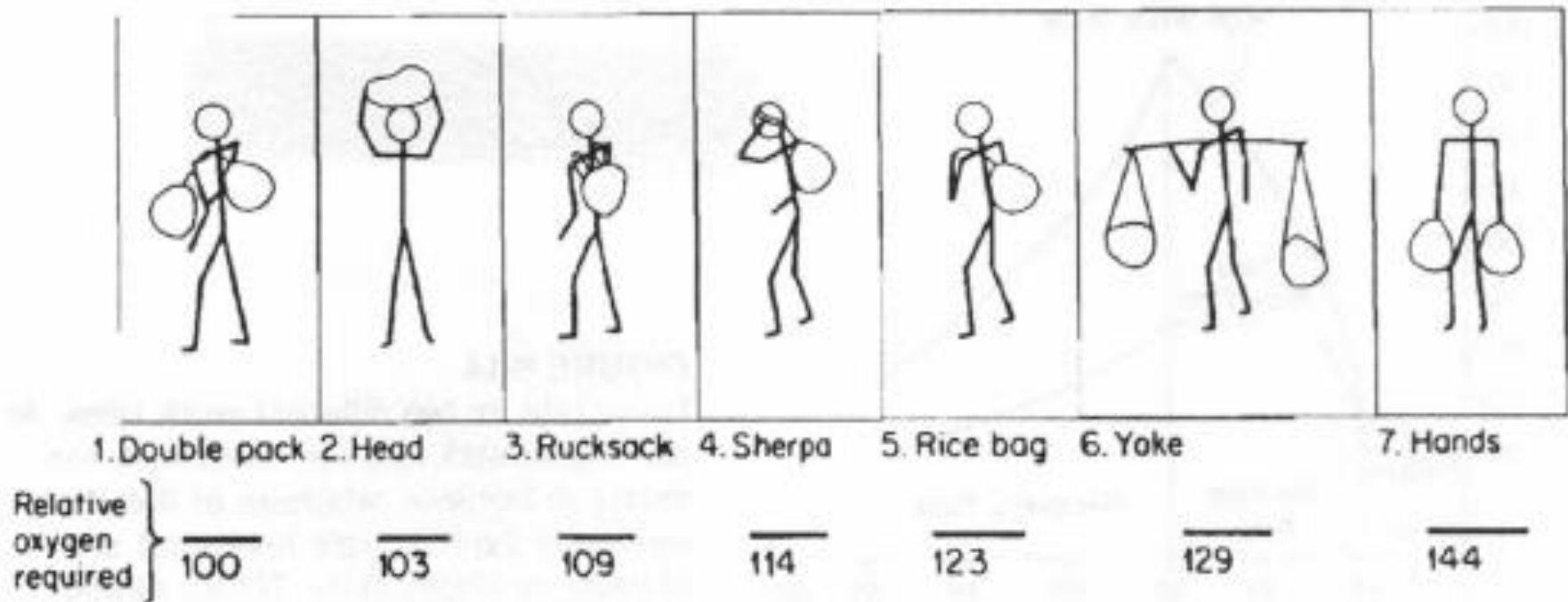


FIGURE 8-12

Relative oxygen consumption of seven methods of carrying a load, with the double-pack method used as a base of 100 percent. This illustrates that the manner in which an activity is carried out can influence the energy requirements. (Source: Adapted from Datta and Ramanathan, 1971.)

FACTORS AFFECTING ENERGY CONSUMPTION: Work Posture

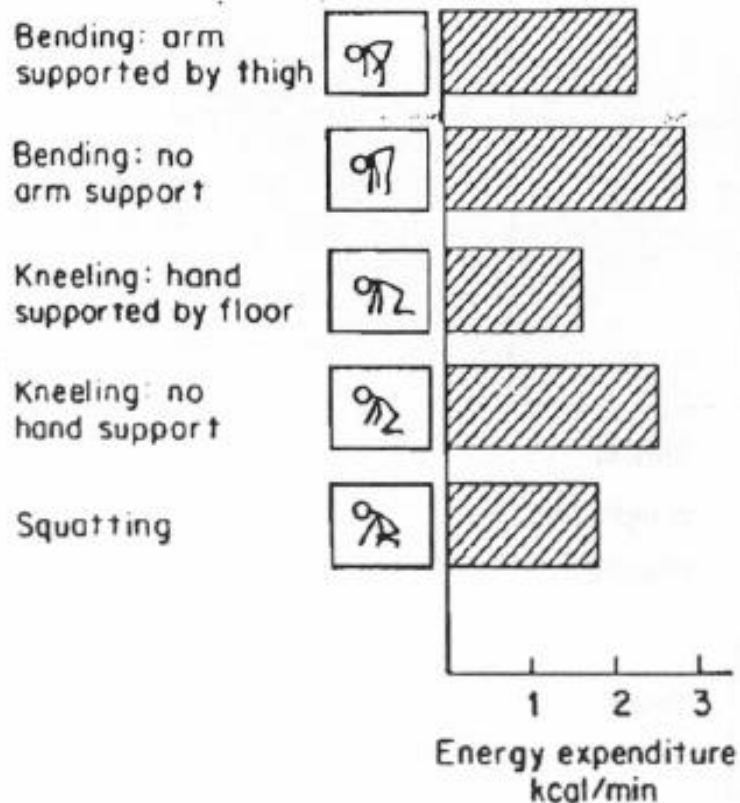
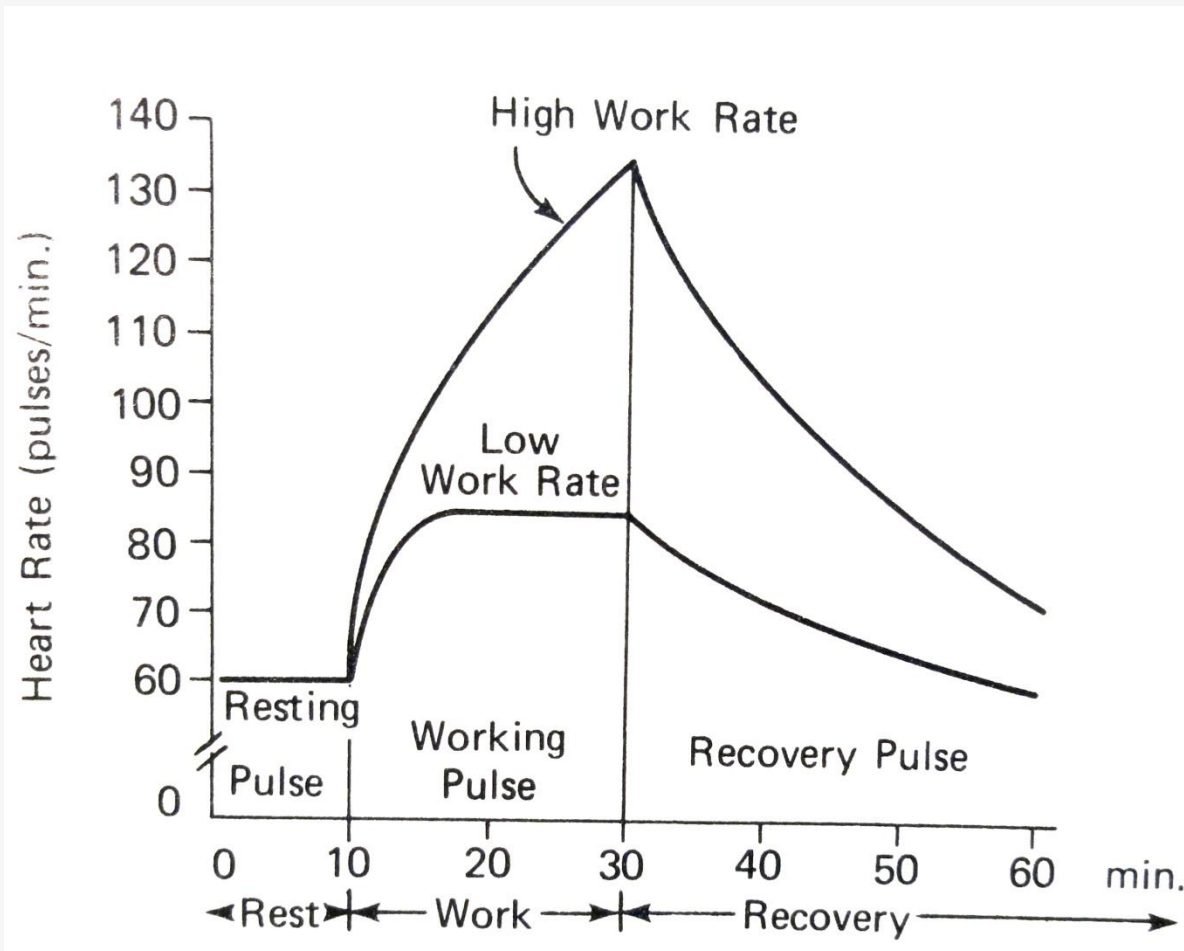


FIGURE 8-13

Human energy expenditures (kilocalories per minute) for five postures used in the task of picking up light objects from ground level. (Source: Adapted from Vos, 1973, Fig. 5.)

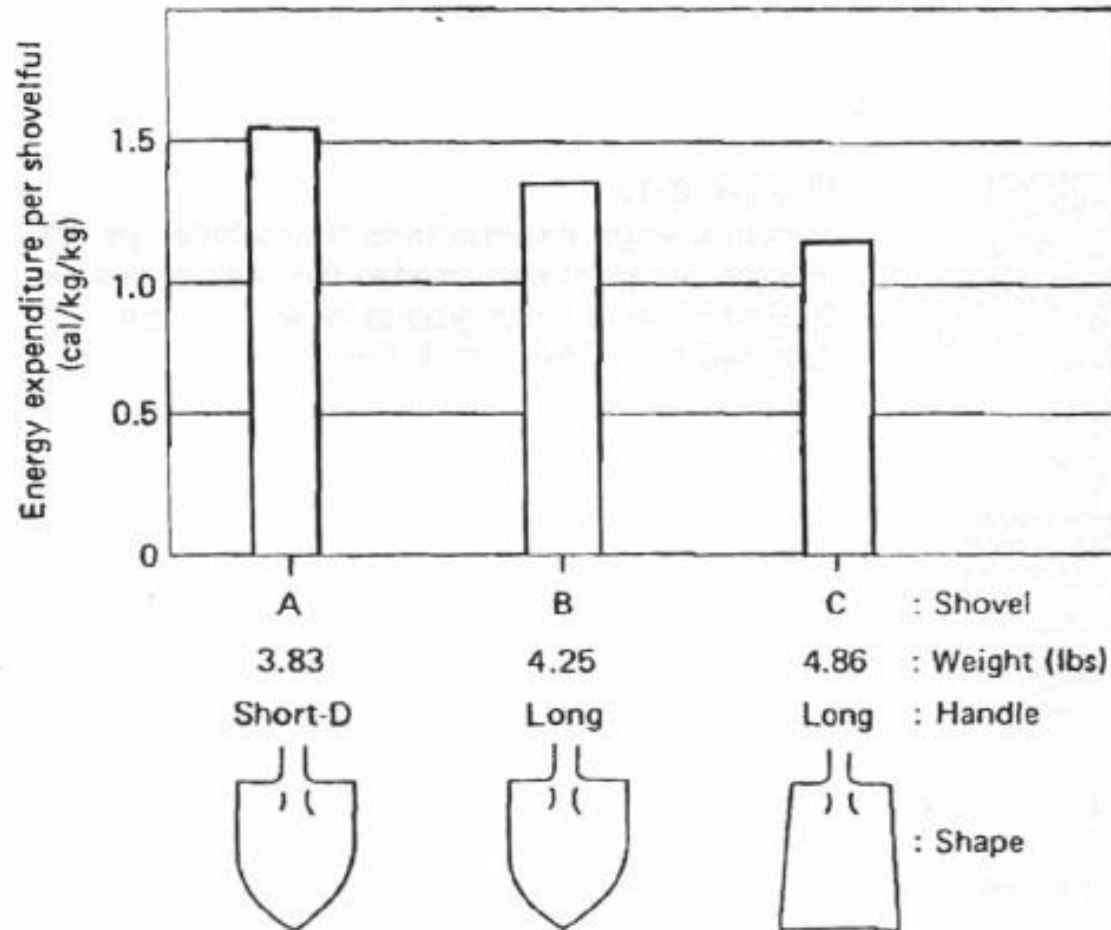
FACTORS AFFECTING ENERGY CONSUMPTION: Work Rate



FACTORS AFFECTING ENERGY CONSUMPTION: Tool Design

FIGURE 8-15

Efficiency of shoveling (energy expenditure per shovelful) as a function of shovel design. (Source: Freivalds, 1986, Fig. 4.)



RECOMMENDED LIMITS

< 35% of MAP (Michael, Hutton and Horvath [1961], Blink [1962]) over an 8-h day.

< 5 kcal/min for men, 3.35 kcal/min for women (Ayoub and Mital [1989]). These are 33% of MAP of man and woman. For a 4 h day they recommended 6.25 and 4.2 kcal/min as the upper limit for man and women.

Brouha 1967 and Suggs and Splinter 1961 recommend that the mean heart rate should not exceed 115 beat/min.

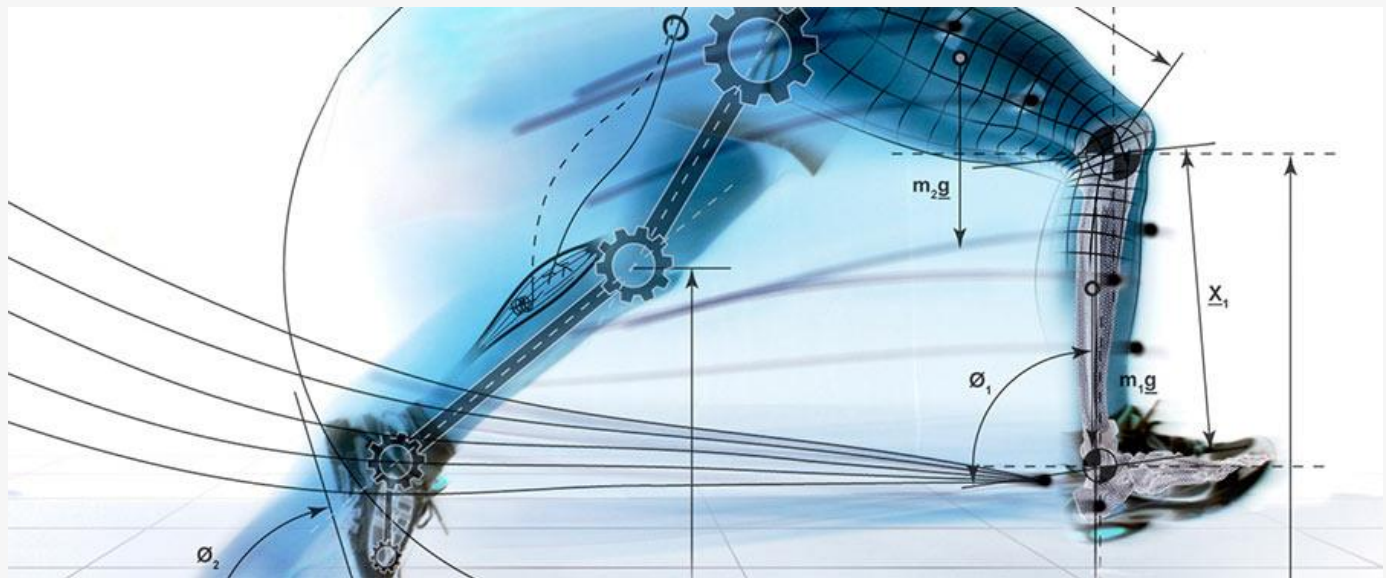


Manual Materials Handling

- Biomechanical Approach
- Physiological Approach
- Psychophysical Approach
- Lifting Tasks
- Carrying Tasks
- Pushing Tasks

BIOMECHANICAL APPROACH

- Physics principles used for analyzing mechanical stresses and forces
- View the body as system of links and joints
- Limited to analyzing infrequent MMH tasks



BIOMECHANICAL APPROACH

- Usually the infrequent lift or push that creates excessive forces
- The goal is to limit task demands to be within the strength capacity and compressive force tolerance of the body.



PHYSIOLOGICAL APPROACH

- Suited for MMH tasks done frequently over a duration of time
- Concerned with the Energy consumption and stresses acting on the cardiovascular system



PHYSIOLOGICAL APPROACH

- Models have been developed, each with their own constraints considering different variables like body weight, gender, vertical start and end position of a lift, dimension of the load and frequency of the handling.



PSYCHOPHYSICAL APPROACH

- Maximum Acceptable Weight of Load (MAWL)
- MAWLS are determined on the basis that 20 to 45 min trial periods overestimate the actual weight decreases people can handle for a 8h day. For males actual acceptable weight decrease 3.4% per hour and 2% for females from the MAWL measured.



LIFTING TASKS

- Influence back injuries more than any other MMH tasks
- Parameters
 - Horizontal Position of Load
 - Height and Range of Lift
 - Method of Lifting from the Floor
 - Frequency of Lifting
 - Object Characteristics



NIOSH LIFTING EQUATION

- 1994 NIOSH Lifting Equation (National Institute for Occupational Safety and Health)
- Lifting Index = Load Weight / Recommended Weight Limit
- NIOSH lifting equation is a tool to prevent work-related low back pain and disability.



NIOSH LIFTING EQUATION

- **Lifting Index (LI)**

The LI is a term that provides a relative estimate of the level of physical stress associated with a particular manual lifting task. The estimate of the level of physical stress is defined by the relationship of the weight of the load lifted and the recommended weight limit.

Lifting Index = Load Weight / Recommended Weight
Limit (RWL)

NIOSH LIFTING EQUATION

- **Recommended Weight Limit (RWL)**

The RWL is defined for a specific set of task conditions as the weight of the load that nearly all healthy workers could perform over a substantial period of time (e.g., up to 8 hours) without an increased risk of developing lifting-related low back pain.

$$\text{RWL} = \text{LC} \times \text{HM} \times \text{VM} \times \text{DM} \times \text{AM} \times \text{FM} \times \text{CM}$$

Load Constant = LC, Horizontal Multiplier = HM,

Vertical Multiplier = VM, Distance Multiplier = DM,

Asymmetric Multiplier = AM, Frequency Multiplier = FM,

Coupling Multiplier = CM

NIOSH LIFTING EQUATION

- **Using the RWL and LI to Guide Ergonomic Design**
 - (1) The individual multipliers can be used to identify specific job-related problems. The relative magnitude of each multiplier indicates the relative contribution of each task factor (e.g., horizontal, vertical, frequency, etc.)
 - (2) The RWL can be used to guide the redesign of existing manual lifting jobs or to design new manual lifting jobs. For example, if the task variables are fixed, then the maximum weight of the load could be selected so as not to exceed the RWL; if the weight is fixed, then the task variables could be optimized so as not to exceed the RWL.
 - (3) The LI can be used to estimate the relative magnitude of physical stress for a task or job. The greater the LI, the smaller the fraction of workers capable of safely sustaining the level of activity.
 - (4) The LI can be used to prioritize ergonomic redesign. For example, a series of suspected hazardous jobs could be rank ordered according to the LI and a control strategy could be developed according to the rank ordering.

NIOSH LIFTING EQUATION

The Revised NIOSH Lifting Equation does not apply if any of the following occur:

- Lifting/lowering with one hand
- Lifting/lowering for over 8 hours
- Lifting/lowering while seated or kneeling
- Lifting/lowering in a restricted work space
- Lifting/lowering unstable objects
- Lifting/lowering while carrying, pushing or pulling
- Lifting/lowering with wheelbarrows or shovels
- Lifting/lowering with high speed motion (faster than about 30 inches/second)
- Lifting/lowering with unreasonable foot/floor coupling (< 0.4 coefficient of friction between the sole and the floor)
- Lifting/lowering in an unfavorable environment (i.e., temperature significantly outside 66-79 degrees F (19-26 degrees C) range; relative humidity outside 35-50% range)

HORIZONTAL POSITION of LOAD

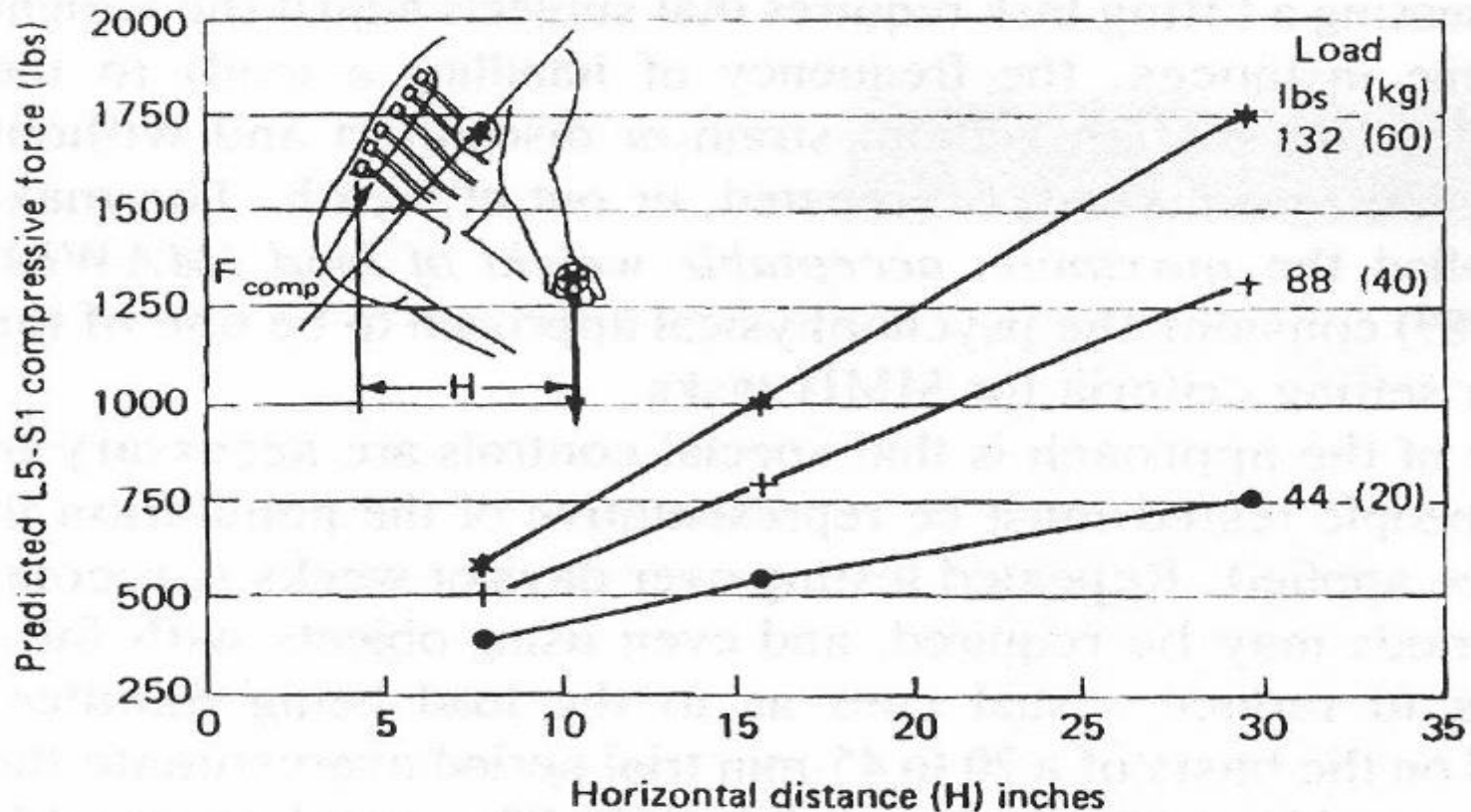


FIGURE 8-25

Effect of weight of load and horizontal distance between the load center of gravity and the L5/S1 disc on the predicted compressive force on the L5/S1 disc. (Source: Adapted from NIOSH, 1981, Figs. 3.4 and 3.5.)

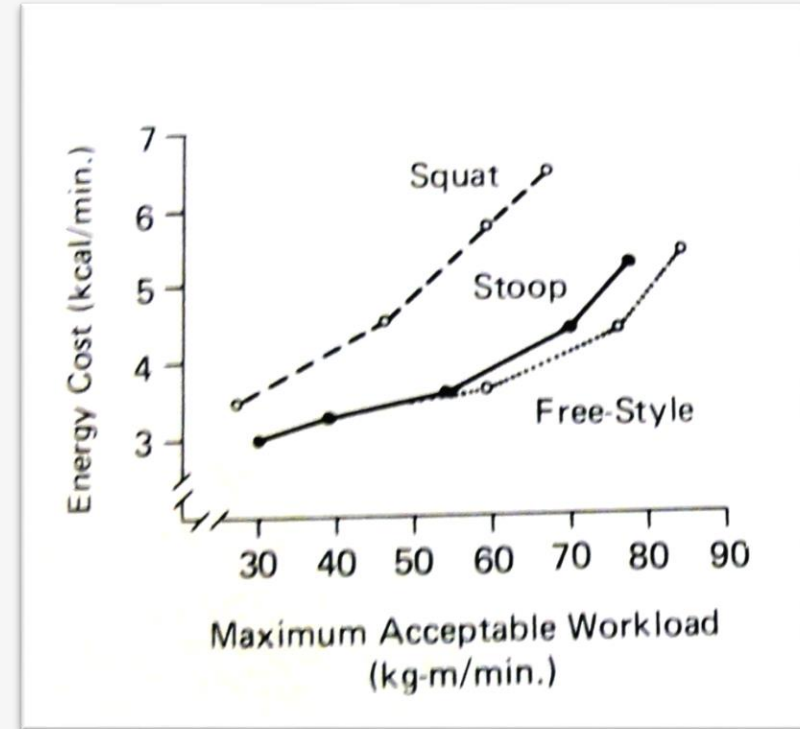
HEIGHT and RANGE of LIFT

- Categories:
 - Floor to knuckle
 - Knuckle to shoulder
 - Shoulder to reach
- Davies (1972) states that the efficient lift range is between 40 and 60 inches.



METHOD of LIFTING

- Free-style (use thighs)
 - Least stressful
 - Requires least energy
- Squat lift (lift with legs)
 - Results in lower biomechanical stresses on the lower back than stoop lifting
 - Requires load to be between the knees
- Stoop lift (lift with back)
 - Toes should touch object and then be lifted to minimize horizontal distance and compressive force
 - With respect to energy expenditure, a stoop lift is less restful than a squat lift



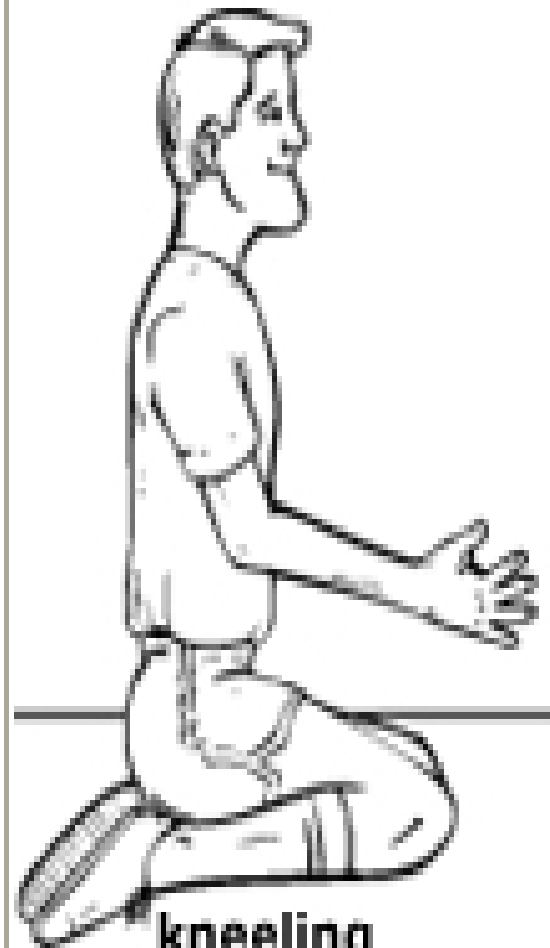
METHOD of LIFTING



stooping



squatting



kneeling

METHOD of LIFTING

Key Prevention Tips

- Avoid lifting and bending whenever you can.
- The best zone for lifting is between your shoulders and your waist.
- Put heavier objects on shelves at waist level.
- Maintain good posture
- Avoid "locking out" the knees
- Use proper lifting techniques
- Exercise and stretch
- Use Team Lifting when appropriate



FREQUENCY of LIFTING

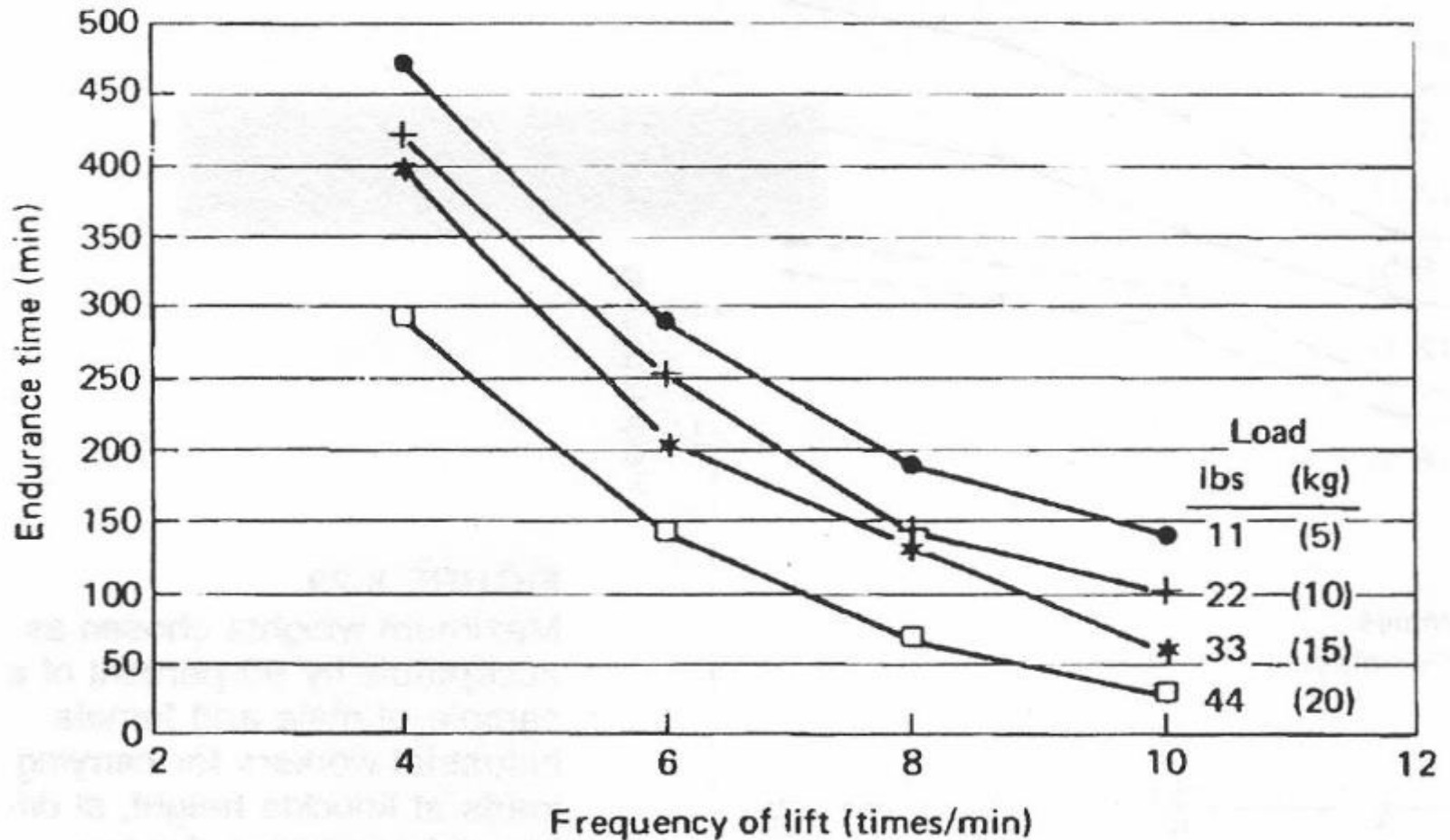


FIGURE 8-28

Endurance time for squat-lifting various loads at various lift frequencies. Lift was from floor to table height. (Source: Genaidy and Asfour, 1989, Fig. 1.)

OBJECT CHARACTERISTICS

- **Object size**
 - Increase height, width, and then length
 - Keep center of gravity of load closer to body
- **Object shape**
 - Collapsible objects (e.g. bags) yield higher MAWL
- **Load distribution and stability**
 - Shifting center of gravity can reduce MAWLs by as much as 31%
- **Handles**
 - Object with handles are safer and less stressful

CARRYING TASKS

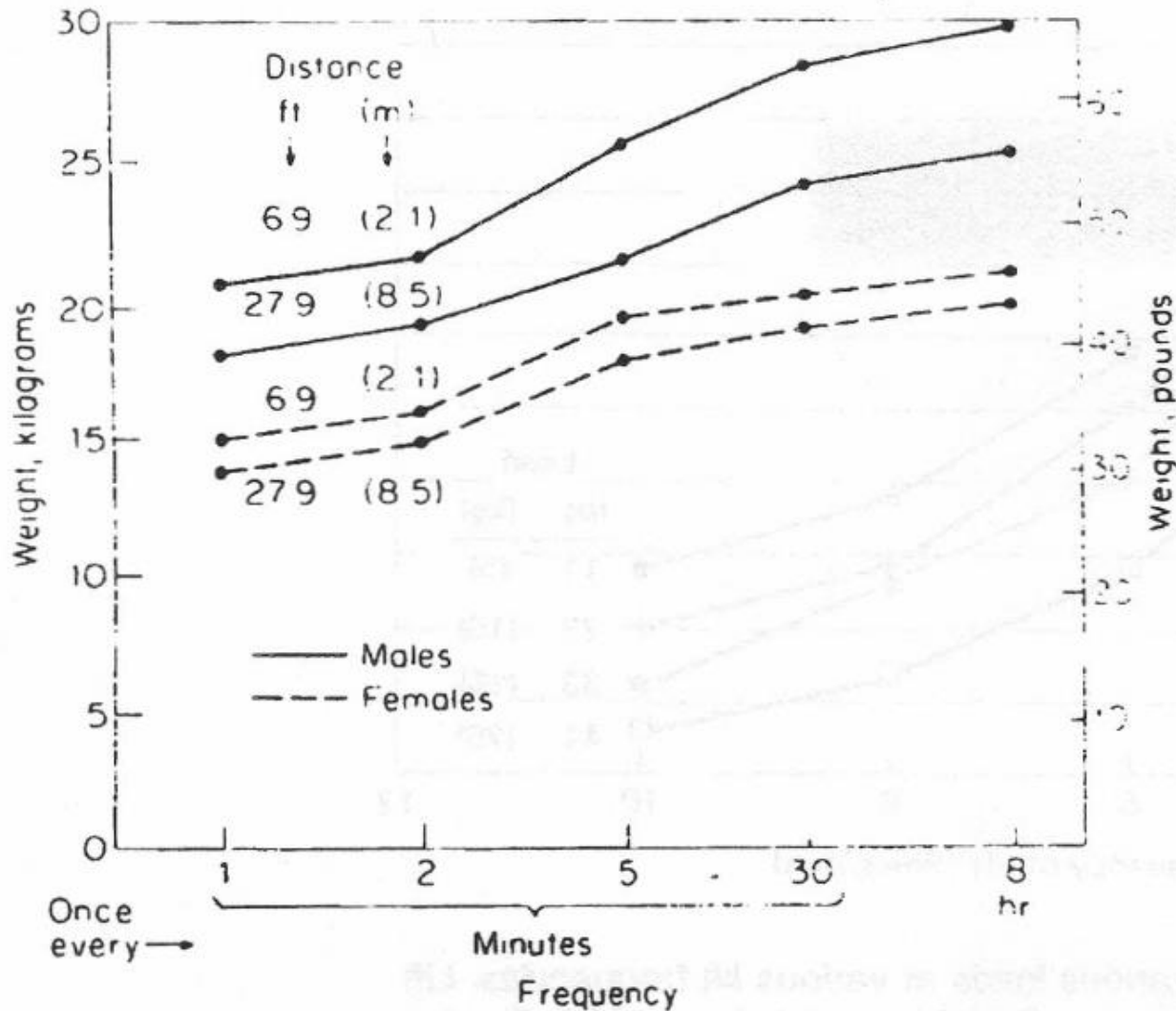


FIGURE 8-29
 Maximum weights chosen as acceptable by 90 percent of a sample of male and female industrial workers for carrying loads at knuckle height, at different frequencies, for two distances. (Source: Snook, 1978, Table 10, p. 980.)

CARRYING TASKS

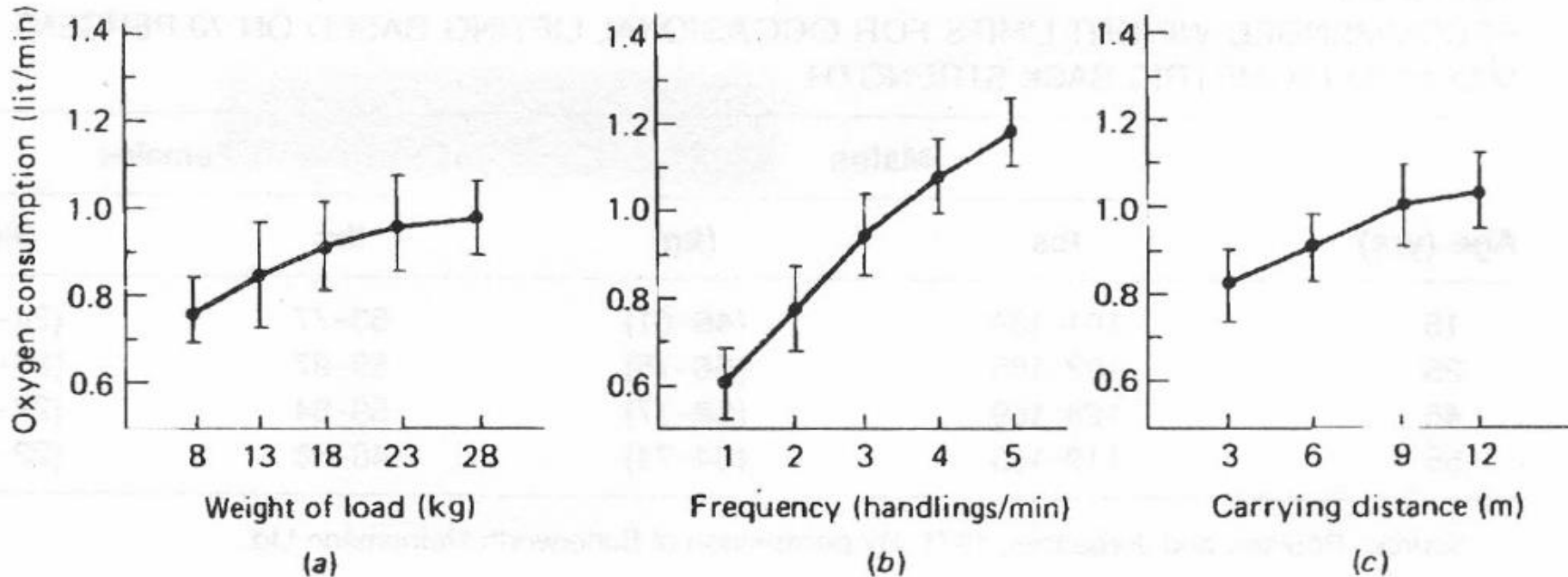


FIGURE 8-30

Effect of weight of load (a), frequency of handling (b), and carrying distance (c) on oxygen consumption for a lifting and carrying task. Data are averaged across values of the other variables. Walking speed was 2.5 mi/h (4 km/h). (Source: Dutta and Taboun, 1989, Figs. 7, 9, and 11.)

PUSHING TASKS

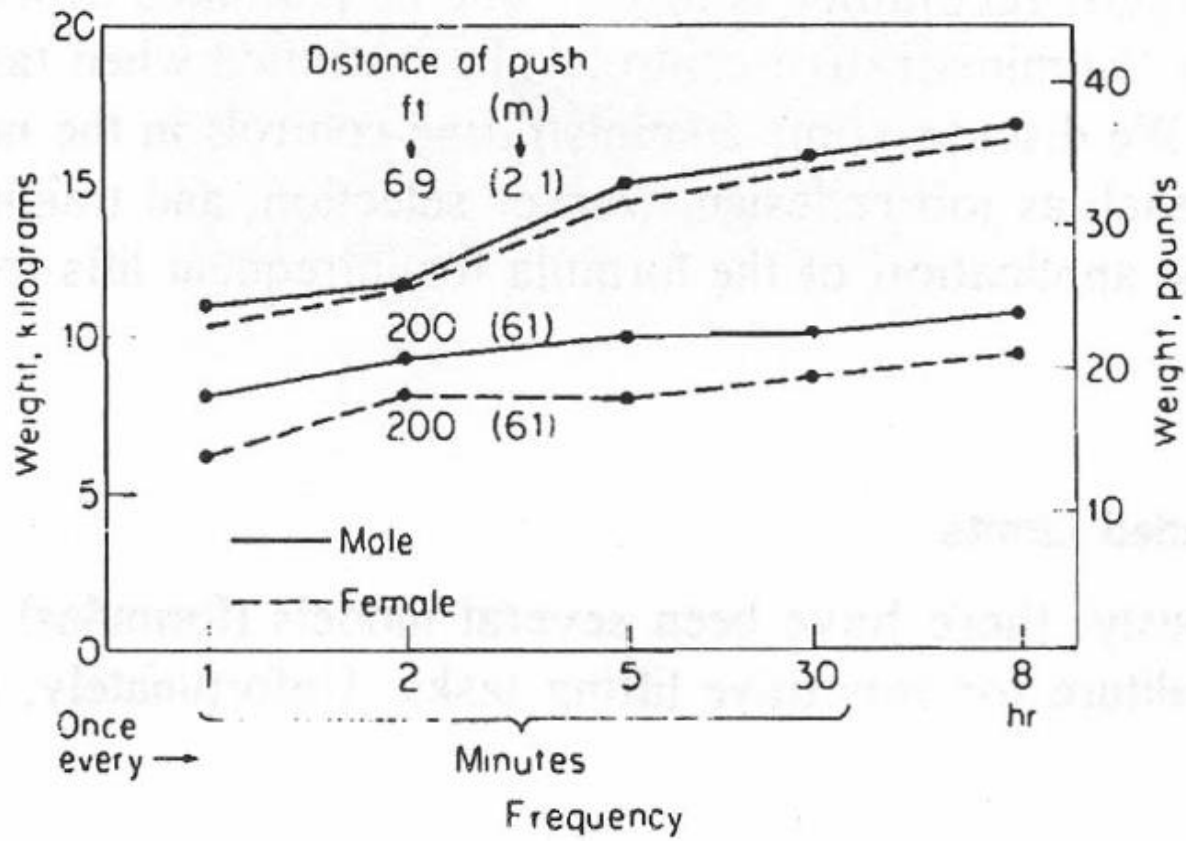
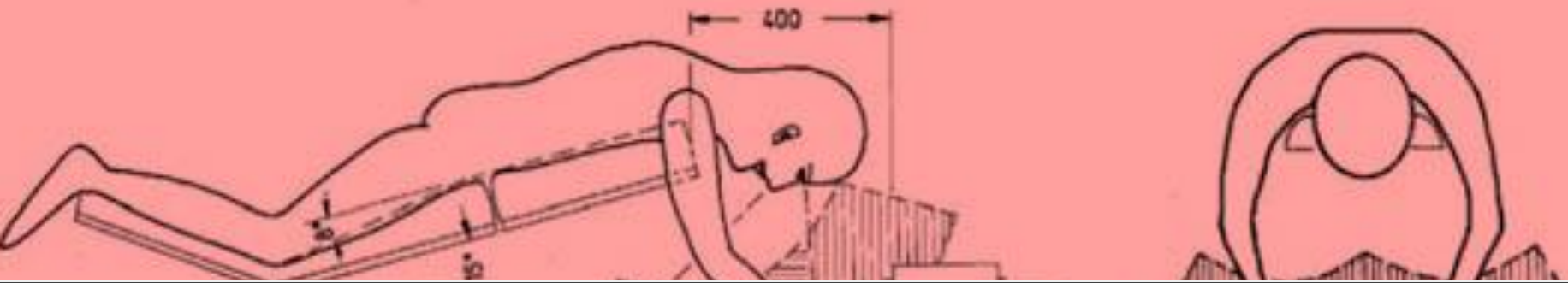


FIGURE 8-31

Maximum weights chosen as acceptable by 90 percent of a sample of female and male industrial workers for a pushing task at shoulder height, at different frequencies, for two distances. (Source: Snook, 1978, Tables 5, 6, 7, 8, pp. 975-978.)





Reducing the Risk of MMH Overexertion

- Job Design
- Worker Selection
- Worker Training

- Decrease the weight of the objects handled
- Use two or more people to move heavy or large objects
- Change the activity; for example, pull or, better yet, push rather than carry
- Minimize horizontal distances between start and end of the lift
- Stack materials no higher than shoulder height

- Keep heavy objects at knuckle height
- Reduce frequency of lifting
- Incorporate rest periods
- Incorporate job rotation to less strenuous jobs
- Design containers with handles that can be held close to the body

Pre-employment Screening Tests

- Back X-ray
- Strength Test
- Medical Exam

Pre-employment Screening Test Characteristics

- Be safe to administer
- Give reliable & quantitative values
- Be related to specific job requirements
- Be practical to administer
- Should predict risk of future injury or illness

WORKER TRAINING

“Enough evidence is available in support of training program effectiveness to warrant its further employment, ***provided those programs are conducted in conjunction with ergonomic job design and employee selection procedures.***”



"The safety training video just arrived."

The
End