Physical Workload

Introduction

Great deal of our work activities require physical effort and the manual handling of materials, supplies and tools.

Stress & Strain

Stress

– Undesirable condition, circumstance, task, or other factor that impinges upon the individual

Strain

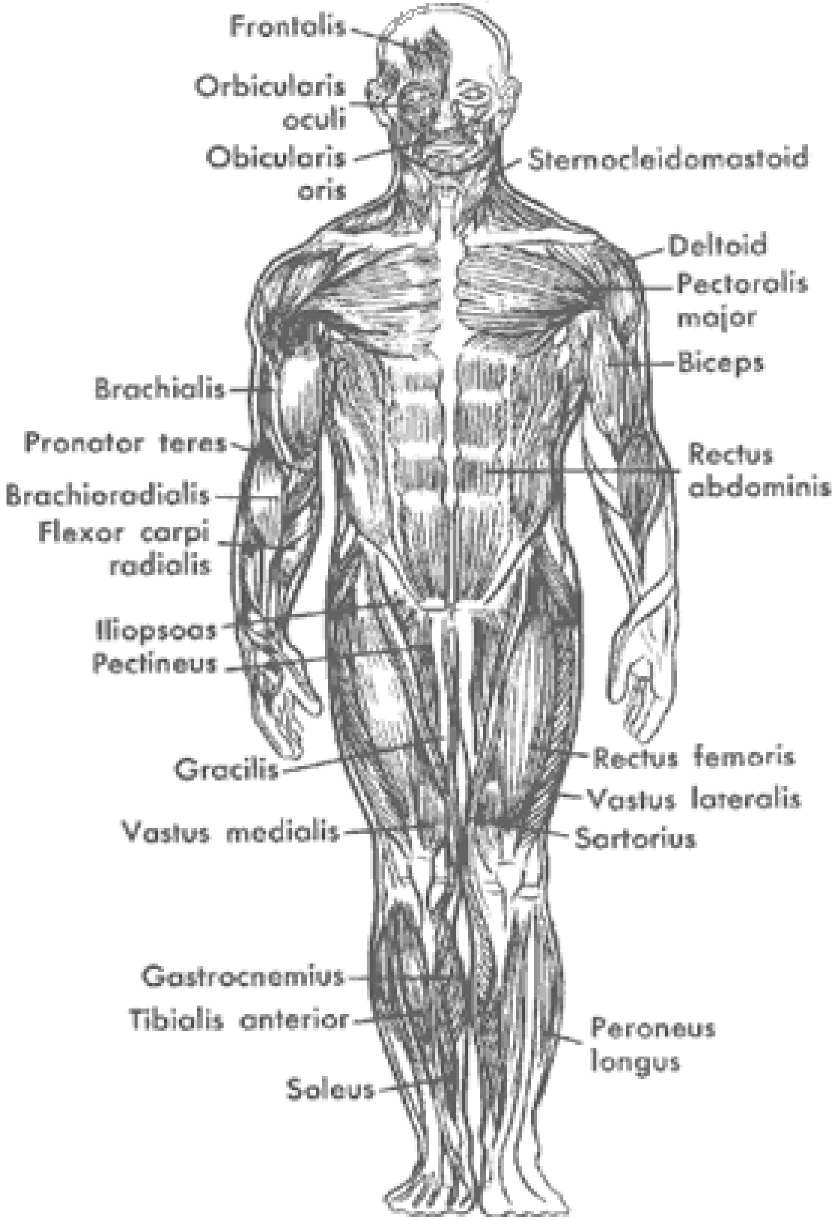
– Effect of the stress on the individual

Muscle Physiology

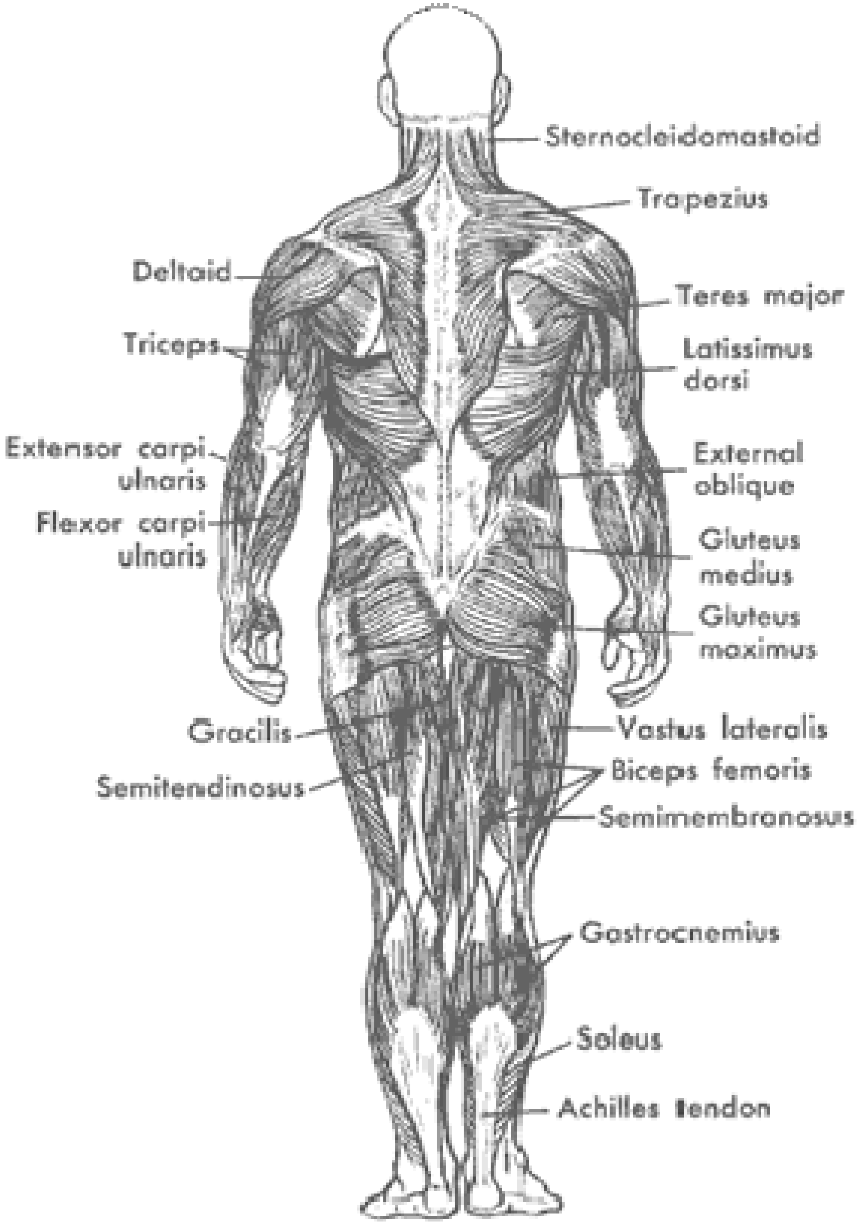
- Nature
- Contractibility
- Control of Action
- Metabolism
  - Anaerobic Glycolysis
  - Aerobic Glycolysis
  - Basal Metabolism

Nature

- > 600 muscles
- > 400 skeletal muscles (in pairs)
- Skeletal muscles are attached to bones by tendons
- Vigorous Activities < 80 pairs
- Contraction causes movement



The Main Anterior Muscles of the Human body



The Main Posterior Muscles of the Human body

Nature

- Several hundred thousands of muscle fibers
- Fibers connected by tissues
- nerve impulses entrance, carried through fibers
- Oxygen & nutrients thru blood vessels permeating muscle tissue

Contractibility

- Muscle fiber
- Contractile unit (Myofibril)
- Myosin & Actin (arranged in bands)
- Slide between each other
  (half length)
- Force = f(# activated muscle fibers)

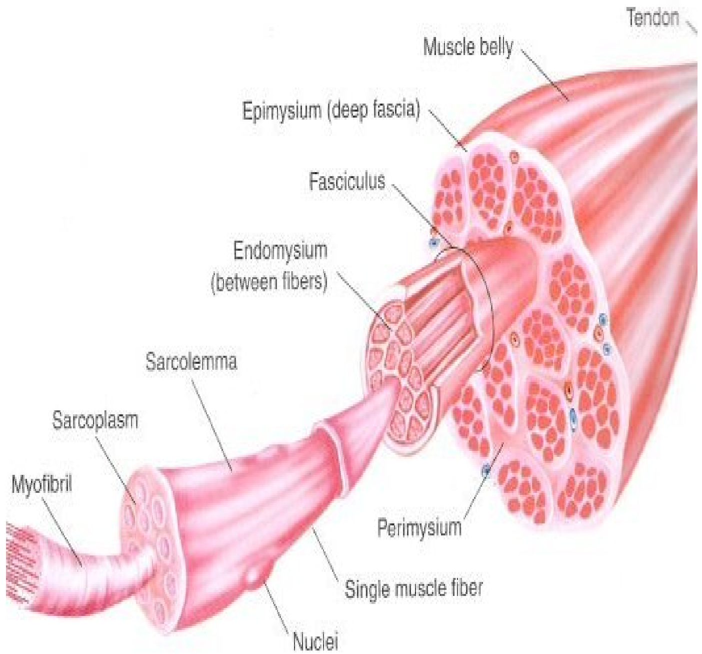
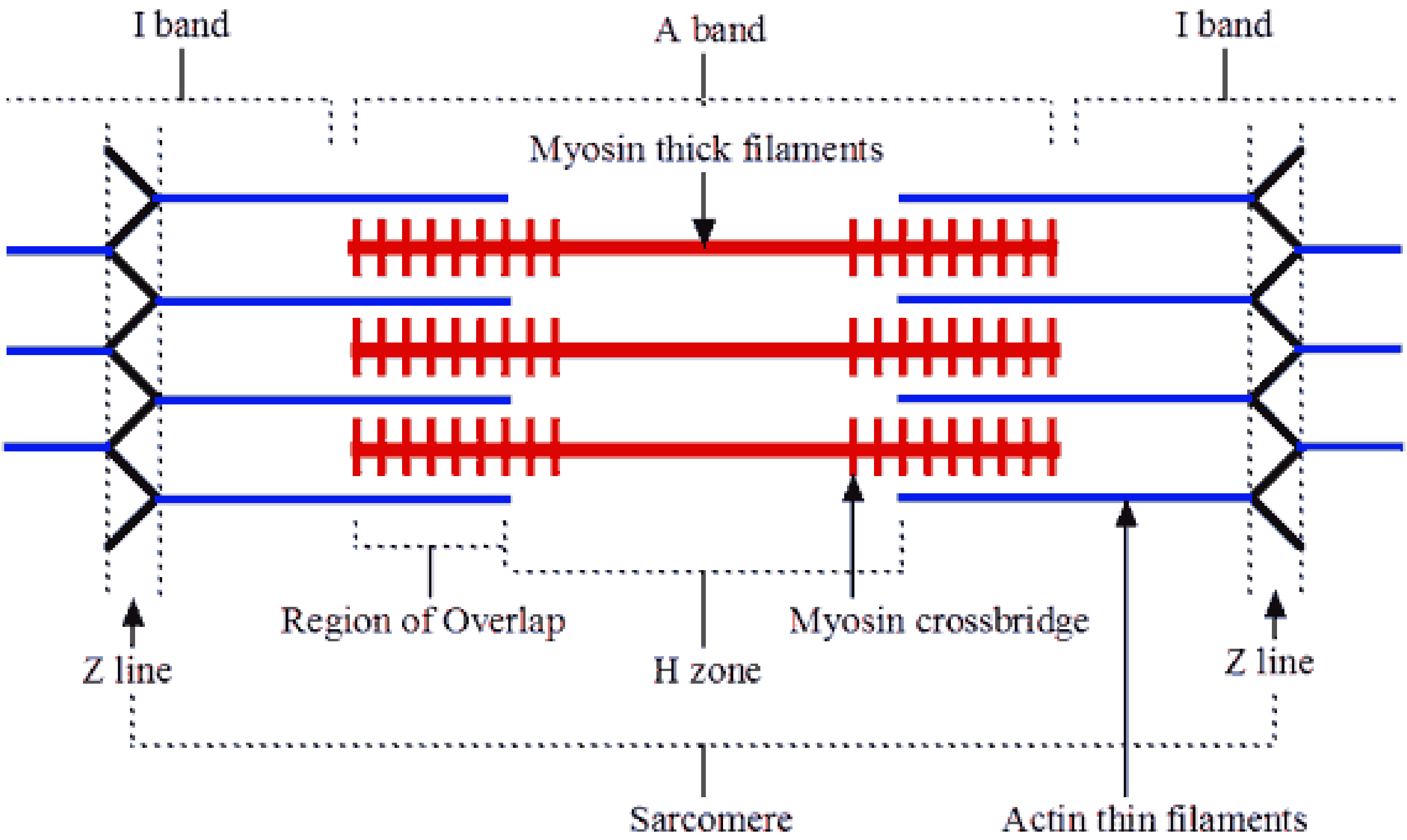


Figure 1: Muscle belly split into various component parts (from Essentials of Strength Training & Conditioning, National Strength & Conditioning Association)

Contractibility



Contractibility

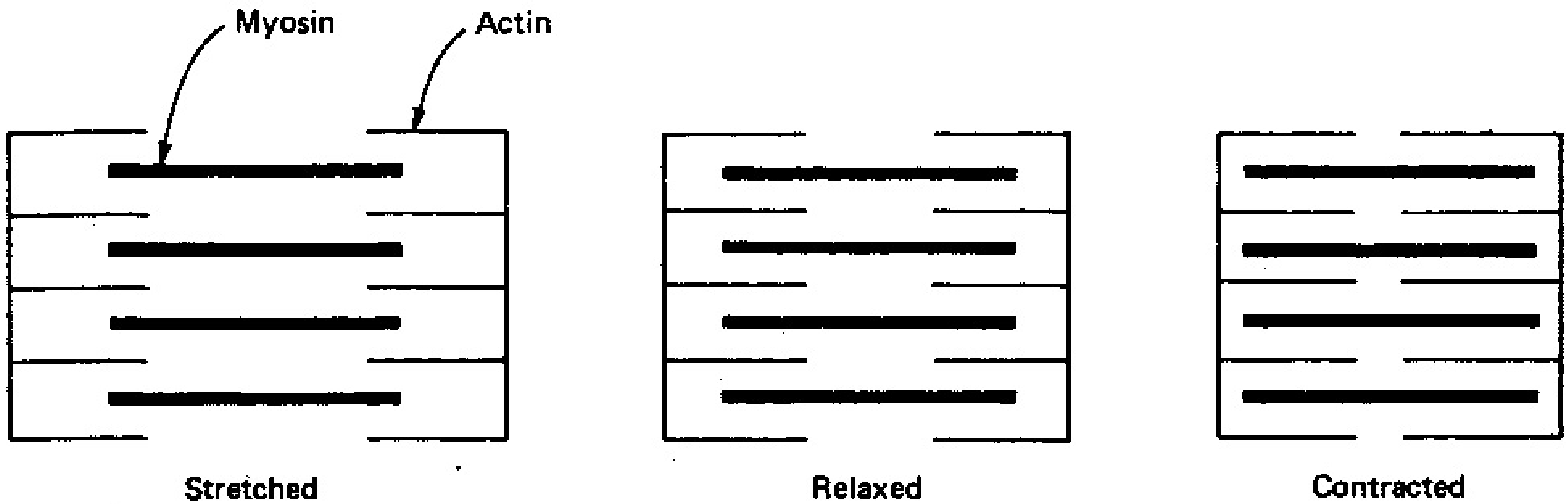


FIGURE 8-1
Schematic drawing of the protein filaments of a myofibril in a stretched, relaxed, and contracted condition. The myosin and actin filaments slide together to cause the muscle to shorten when contracted.

Control of Action

- Activation
  - Motor nerves emanating from the spinal cord
  - Conscious vs. Reflex
- Motor Unit
  - Motor-nerve fiber + group of muscle fibers

Metabolism

- Energy to slide actin over myosin
- Food (carbs & fat)
  - Carbs to Glucose (in the liver)
- Energy stored in ATP
  - Adenosine Triphosphate
- ATP to ADP
- Creatinine Phosphate (CP)
  - Immediate energy for a muscle
  - Energy store for ATP (short time)

Anaerobic Glycolysis

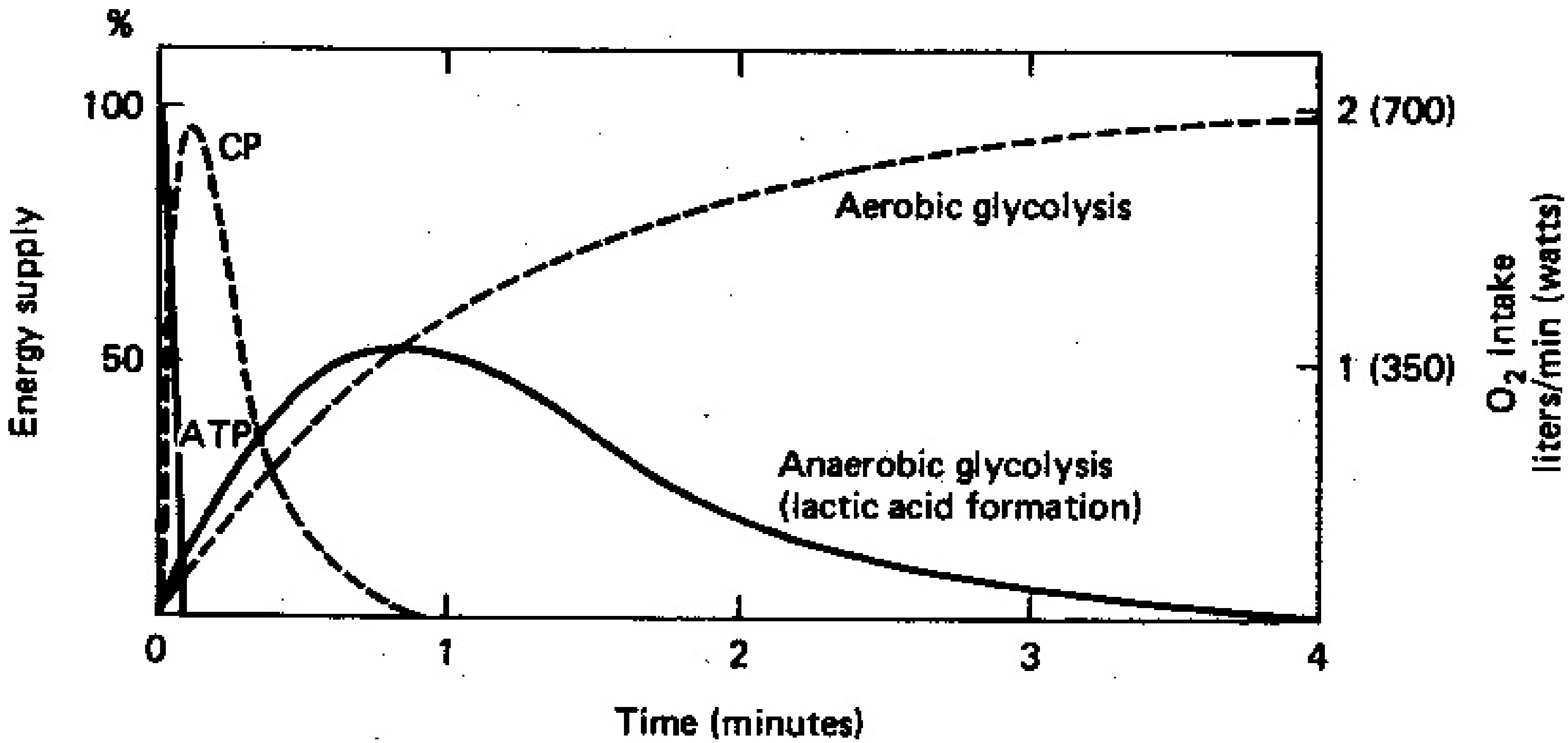
- Initial breakdown of glucose and liberation of energy does not require oxygen
- Glucose into pyruvic acid
- Pyruvic acid into lactic acid
- Fatigue

Aerobic Glycolysis

- Pyruvic acid into CO_2 & H_2O
- 20 times the energy by anaerobic glycolysis
- Strenuous bout of physical activity converts lactic acid into pyruvic acid
- + O_2 (pyruvic acid undergo aerobic glycolysis)
- Energy used to build up ATP and CP stores

FIGURE 8-2

Sources of energy during the first few minutes of moderately heavy work. High-energy phosphate stores (ATP and CP) provide most of the energy during the first seconds of work. Anaerobic glycolysis supplies less and less of the energy required as the duration of work increases and aerobic metabolism takes over. (*Source: Jones, Moran-Campbell, Edwards, and Robertson, 1975.*)



Basal Metabolism

- Food → Heat + Mech. Energy

  70% 30% - large muscles

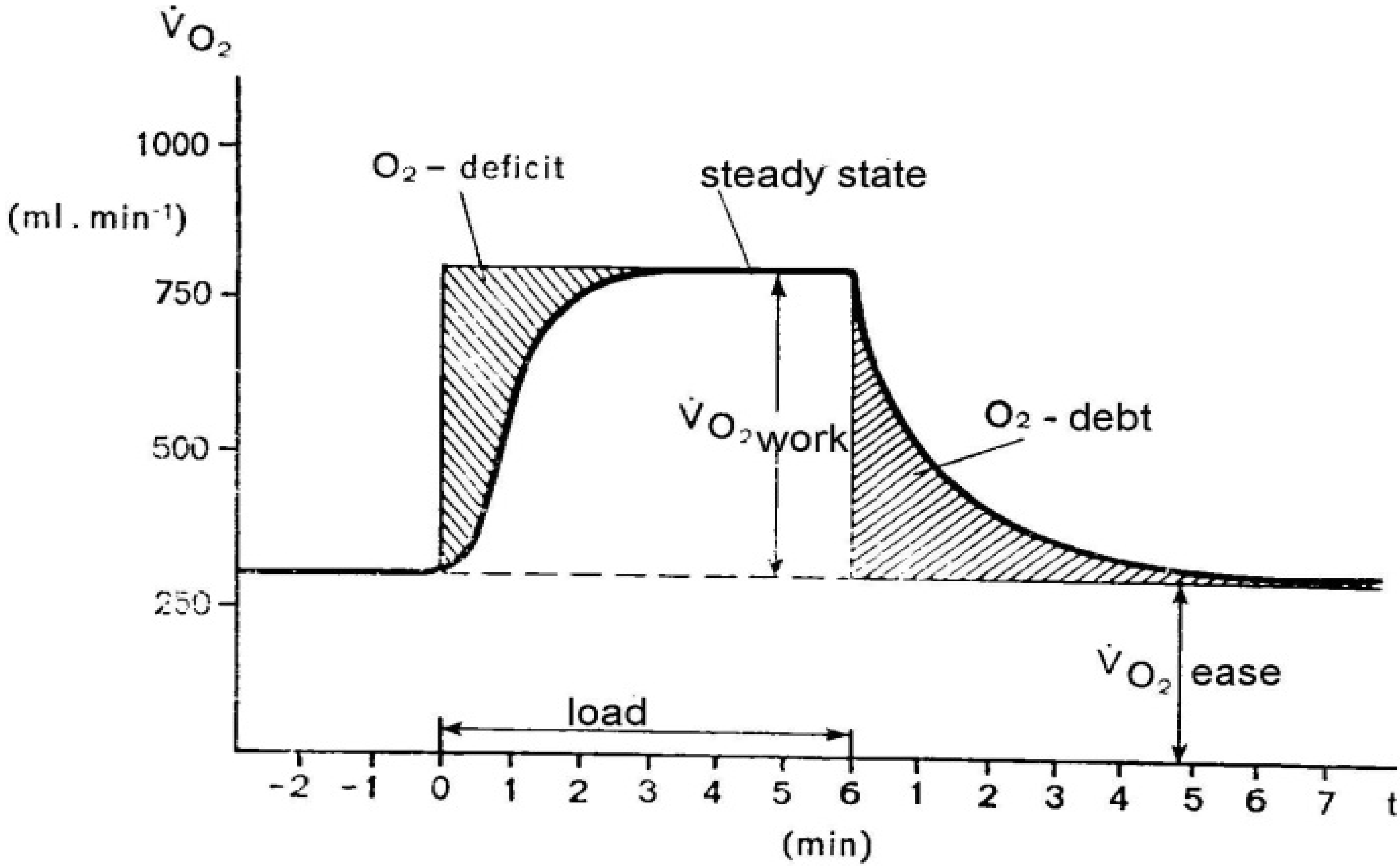
- ***BMR***: basic metabolic rate:
  - amount of energy per unit time needed to sustain life
    - Body size
    - Gender
    - Age

Work Physiology – Respiratory Response

- Additional O_2 for aerobic glycolysis
- At Rest < **0.5** L/min
- Extremely heavy work ≅ **5** L/min
  - – breathing rate
  - – volume of inspired air
- Lag >> anaerobic glycolysis
  - – ATP & CP stores depletion (***debt***)

Work Physiology – Respiratory Response

- Oxygen Debt:
  - O_2 required by the muscles after beginning of work
  - over and above supplies during work activity
  - Has to be repaid


$\dot{V}_{O_2}$
1000
750
500
250
$(ml . min^{-1})$
O_2 - deficit
steady state
$\dot{V}_{O_2}$ work
O_2 - debt
$\dot{V}_{O_2}$ ease
load
-2 -1 0 1 2 3 4 5 6 1 2 3 4 5 6 7 t
(min)

Work Physiology – Cardiovascular Response

O_2 + glucose $\xrightarrow{\text{Blood}}$ Muscles

[O_2 + glucose] $\Rsh$ Blood $\Rsh$ Cardiac Output $\underset{5}{\overset{25}{\uparrow}}$

Cardiac Output $\rightarrow$ heart rate

$\hookrightarrow$ stroke volume

Work Physiology – Cardiovascular Response

- Cardiac Output
  - Rest 5 L/min
  - Heavy work > 25 L/min

- At 40% of max Capacity
  - Stroke volume stabilizes
  - HR continue to increase

Work Physiology – Cardiovascular Response

Catecholamines → Strengthen heart beat

Adrenal Glands → blood pressure ↑

Greater strain on the heart

blood pressure ↑ → blood to the heart ↑

Work Physiology – Cardiovascular Response

Redistribution of Blood Flow

	Blood Flow Distribution (%)	
Part of the Body	**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

Measures of Physiological Strain

Overall Level Physical work & Stress placed on the Body

- Oxygen Consumption (***uptake***)
  - Max. Aerobic Power (**MAP**)
- Heart Rate
- Catecholamines

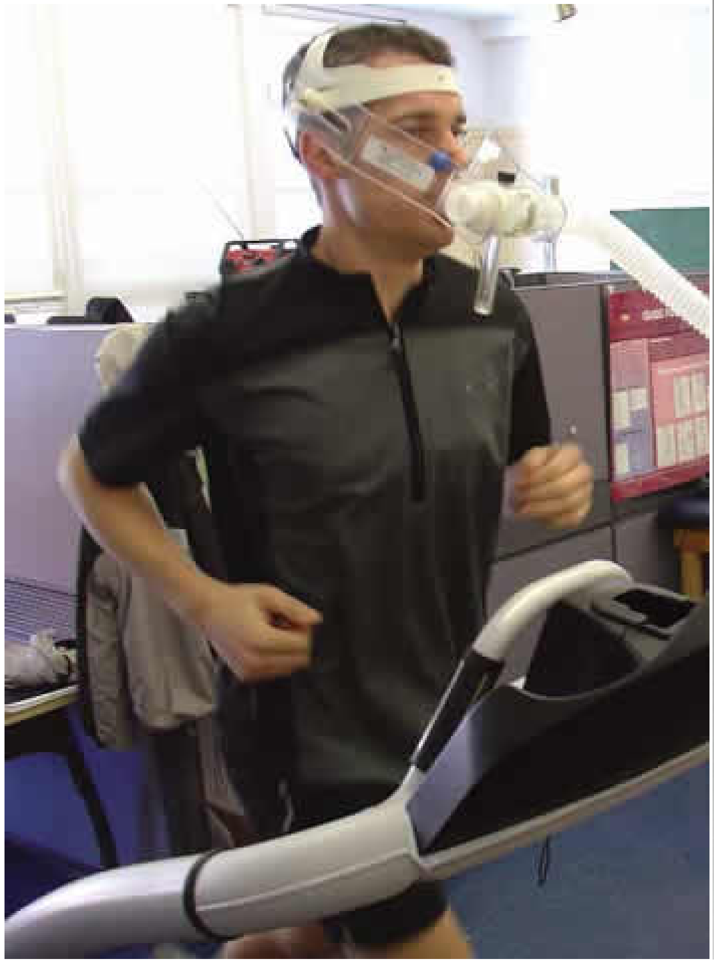
Local Strain

- Muscle Activity

Intrusive & Expensive

- Subjective Measure of Exertion

Oxygen Consumption



Oxygen Consumption

- 1 liter of O_2 liberates 5 kcal of energy
  - **Oxygen α Energy**
- Inspired air per minute
  - Air contains 21% Oxygen
  - Analyze expired air for % O_2
  - O_2 uptake is determined

MAP

- O_2 levels off at ***maximum O_2 uptake***
- Energy metabolism is largely anaerobic
- Lactic acid builds up in blood and muscles' tissues

MAP

- The Higher person's MAP the greater the efficiency of the cardiovascular system
- Age, Sex, Genetics, and Physical Training
- Measuring MAP

Age, Gender and MAP

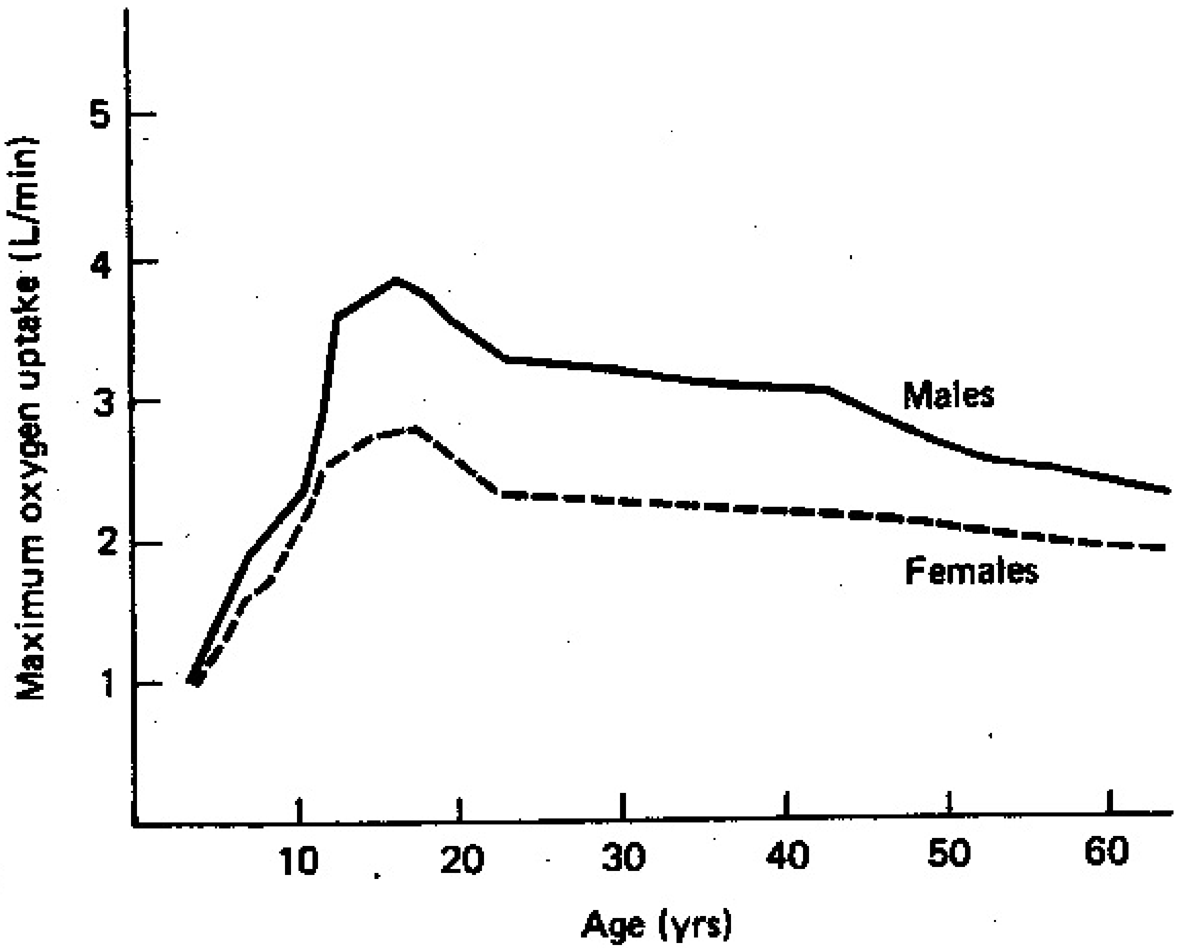


FIGURE 8-5
Mean maximum oxygen uptake (also called maximum aerobic power) in males and females as a function of age. (*Source: Astrand, Astrand, Hallback, and Kilbom, 1973.*)

Heart Rate

- O_2 consumption and HR
  - Directly related (***linear***)
  - Varies with people
- O_2 consumption
- Energy is determined

Heart Rate

- Each person should be calibrated
  - Dynamic workload
  - Static workload (higher HR at any level of O_2 consumption)

- HR is best used as O_2 consumption predictor after stroke volume stabilizes (moderate to heavy work)

Heart Rate – other influences

- Emotional stress
- Fatigue
- Heat stress

Heart Rate – Application

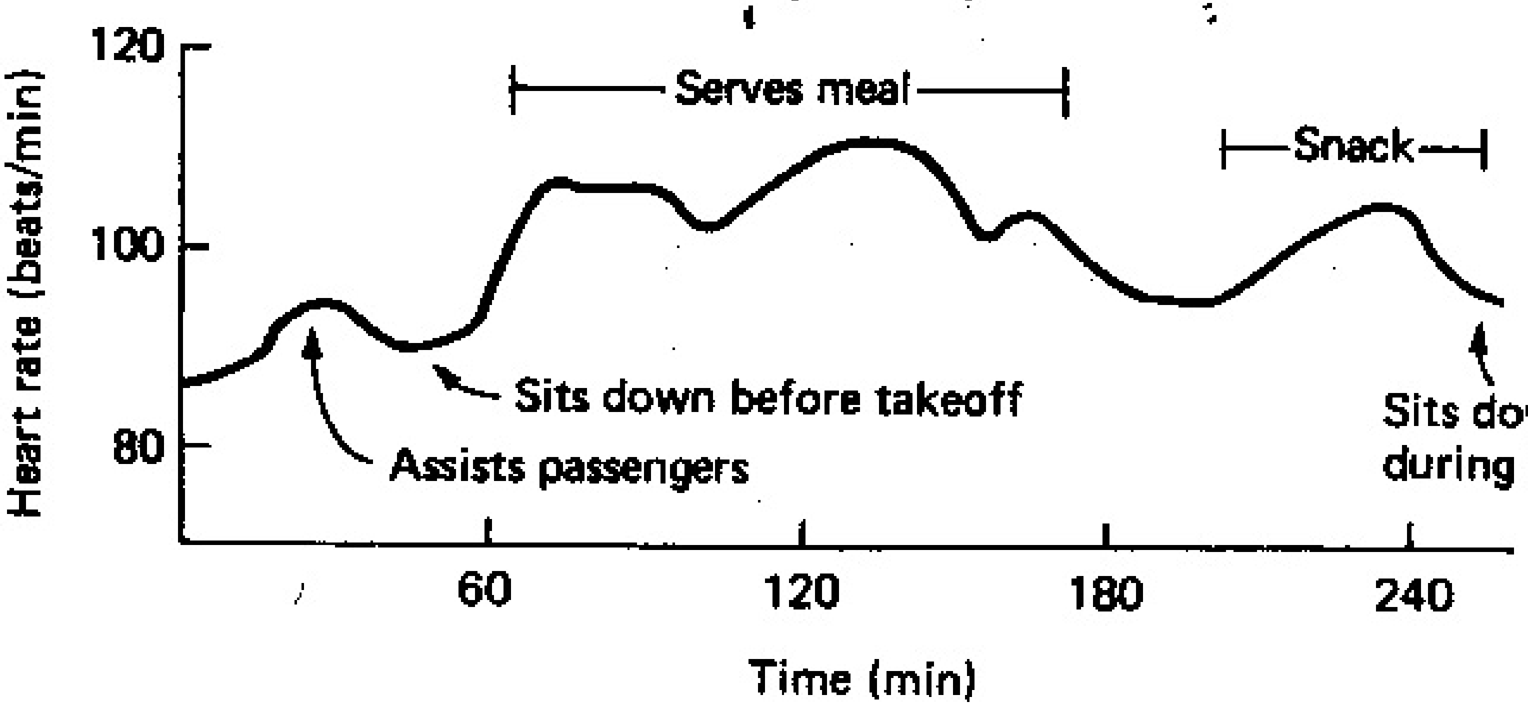
- Continuous sampling of HR over a workday or task
  - General indicator of physiological stress
  - w/o reference to O_2 consumption or energy expenditure

- HR recovery curve

Heart Rate

FIGURE 8-6

Continuous record of an airline flight attendant's heart rate over a 4-h flight. Such records can be useful as general indicators of physiological stress. (*Source: Kilbom, 1990, Fig. 21.8.*)



Catecholamines

- Secretion by adrenal gland
  - Epinephrine & norepinephrin
- Every two hrs
- Measure of Occupational Stress

Local Muscle Activity

- Physiological strain of individual muscles or muscle groups

- Electromyography (**EMG**)

EMG

- Electrodes
- Data Logger
- Recording electrical activities
- EMG signal analysis
  - Amplitude (% of MVC EMG)
  - Frequency

EMG

FIGURE 8-7
Electromyograms recorded for four muscles of a subject maintaining a constant torque of 60 and 15 ft·lb (8.3 and 2.1 kg·m). The sum of the four values is an index of the total amount of energy expended. (*Source: Adapted from Khalil, 1973, Fig. 3.*)

Foot-pounds	Deltoid	Biceps	Triceps	Brachioradialis	Total
60	4.7	30.1	7.1	19.7	63.6
15	1.9	9.7	1.2	5.1	17.9

EMG

- Higher correlation between EMG activity and muscular force

- Fatigue
  - Increased activity in the low frequency range
  - Reduced activity in the high frequency range

Subjective Measure of Exertion

- Borg Scale
  - ***RPE*** (rating of perceived exertion)

- Dynamic Work

- Ratings 6 to 20 are linearly related to Heart Rate
  - HR = 10 * rating

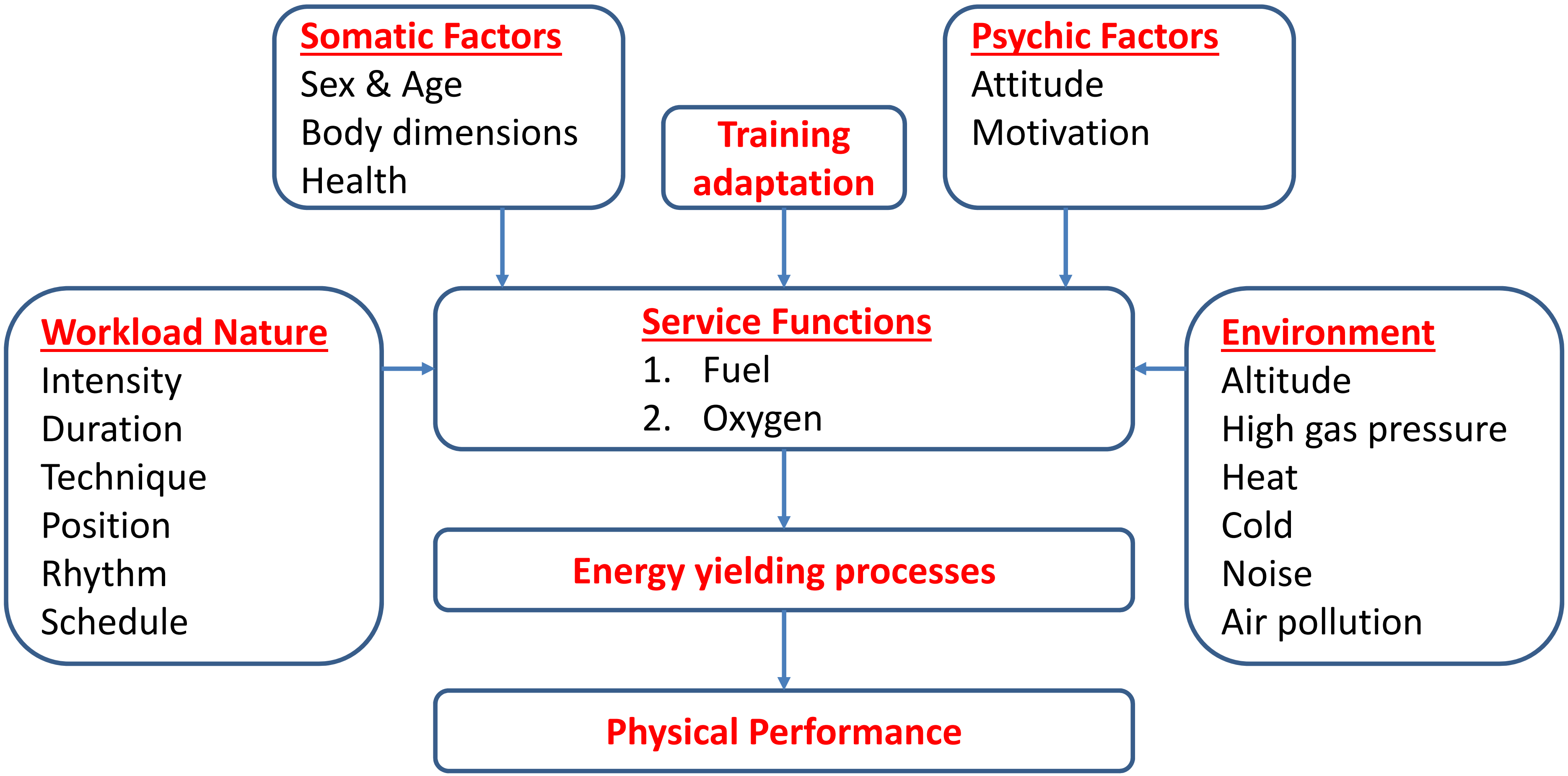
Borg-RPE Scale

6. No exertion
7.
8. Extremely light
9. Very light
10.
11. Light
12.
13. Somewhat hard

Borg-RPE Scale

14.
15. Hard (heavy)
16.
17. Very hard
18.
19. Extremely hard
20. Maximal exertion

Major Factors Influencing Power & Capacity for Physical Activity



Work Efficiency

- Energy expended
  - Much of it heat (≅ 70%)
  - Some unproductive static efforts (e.g. holding)
  - Useful work

$$\text{Efficiency}\,(\%) = \frac{\text{work output}}{\text{energy consumption}} \times 100$$

Work Efficiency

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

Effect of Equipment on Efficiency

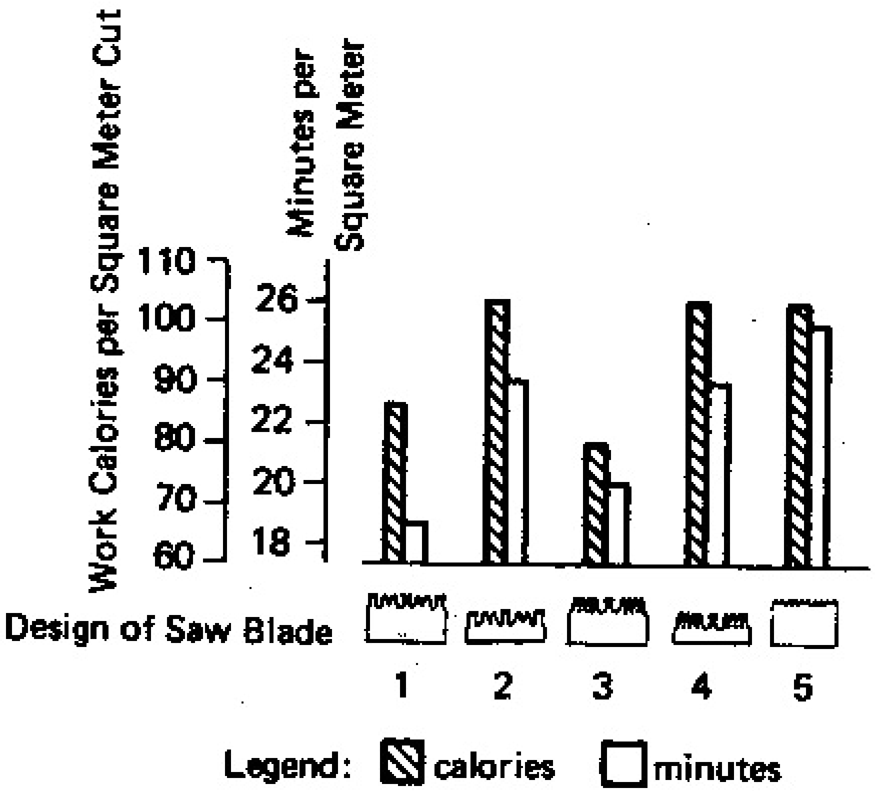


FIGURE 8-9
Calories expended and time spent in cutting a standard unit of work with five timber saws (unit of work: 1 m^2 of area cut). Saws 1 and 3 were clearly most efficient. (*From Grandjean, 1988, Fig. 73, p. 89.*)

Efficiency as Energy Consumption per unit of Walking Effort

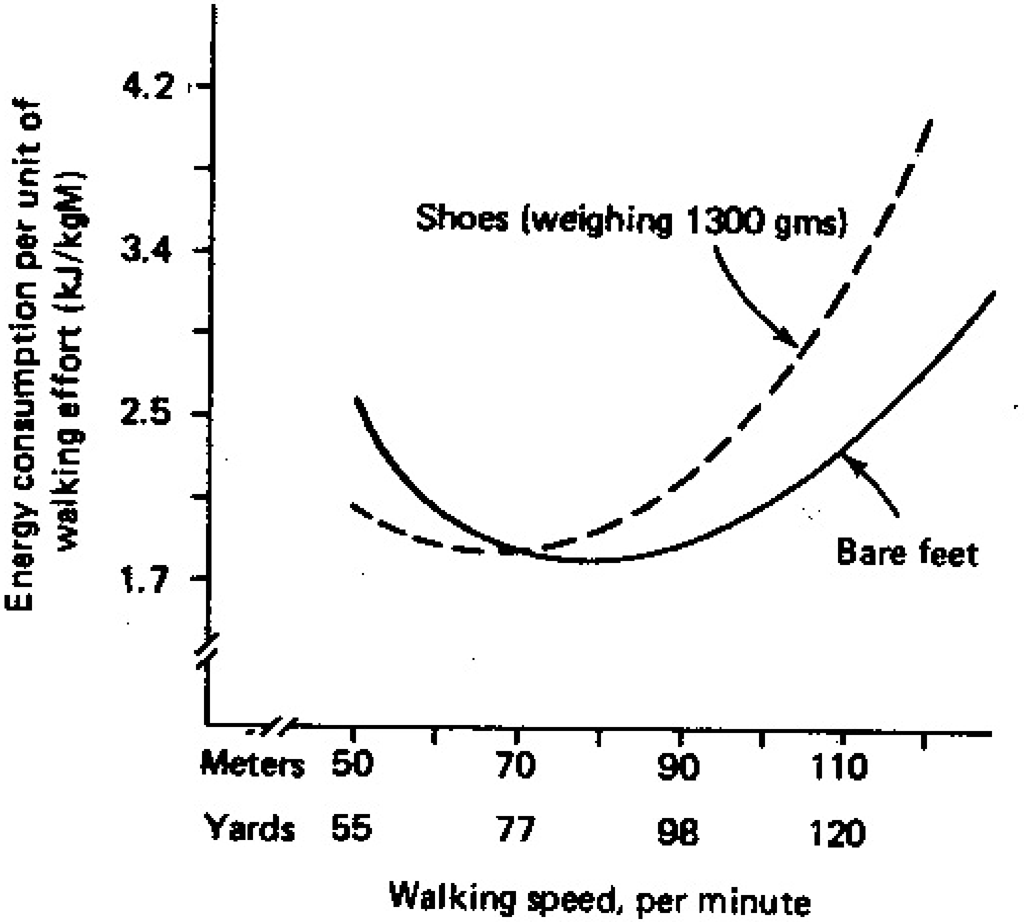


FIGURE 8-10
Efficiency, expressed as energy consumption (kJ) per unit of walking effort (kg-m), of walking with shoes and bare foot as a function of walking speed. (*Adapted from Grandjean, 1988, Fig. 75.*)

Energy Consumption

Activity	Physiological Cost (kcal/min)
Sleeping	1.3
Sitting	1.6
Standing	2.25
Walking (level)	2.1
Cleaning / ironing	2.0 – 3.0
Cycling (16 km/h)	5.2

Energy Consumption

Occupation	Energy Expenditure (kcal / day)		
	Mean	Min	Max
Laboratory technicians			
Males	2840	2240	3820
Females	2130	1340	2540
University students			
Males	2930	2270	4410
Females	2290	2090	2500
Males only			
Construction workers	3000	2440	3730
Steel workers	3280	2600	3960
Coal miners	3660	2970	4560
Housewives (middle age)	2090	1760	2320

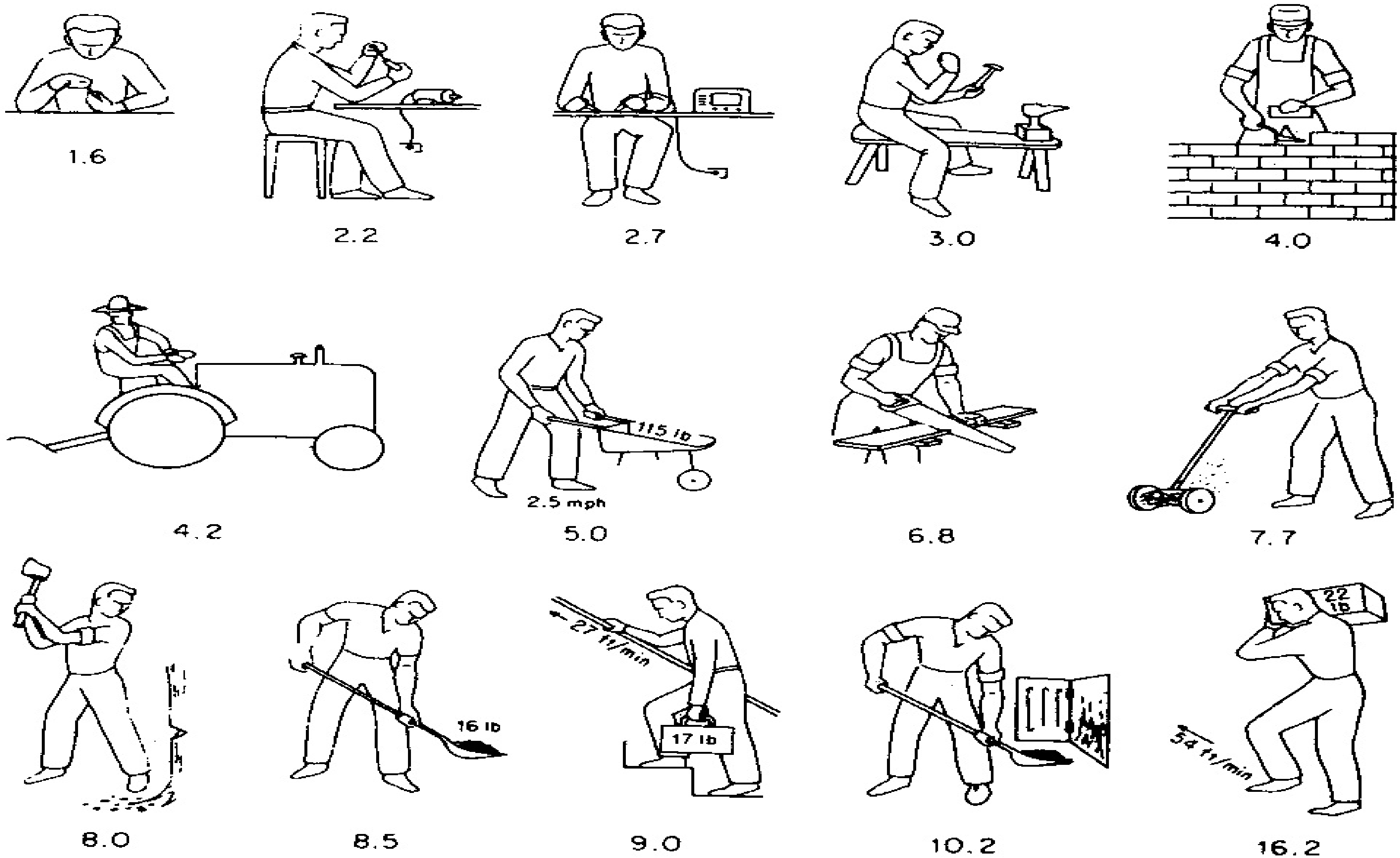


FIGURE 8-11
Examples of energy costs of various types of human activity. Energy costs are given in kilocalories per minute. (*Source: Passmore and Durnin, 1955, as adapted and presented by Gordon, 1957.*)

Grades of Work

Grade of work	Energy expenditure, (kcal / min)	Energy expenditure, 8 h (kcal / d)	HR, (beats / min)	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

Grades of Work

- Most occupations
  - light or moderate work
  - maximum values mostly at heavy work

Factors Affecting Energy of Work

- Methods of Work
- Work Posture
- Work Rate
- Tool Design

Methods of Work

- Good posture balance
- Minimal effect on body’s center of gravity

Methods of Work

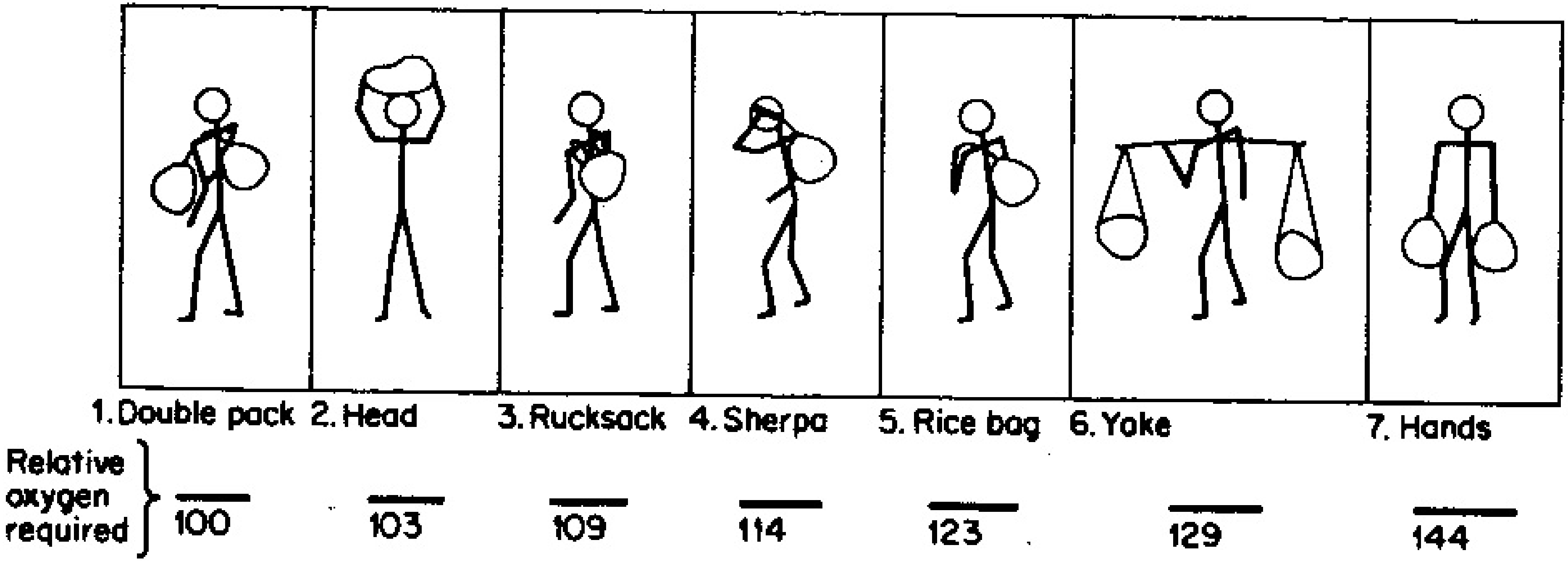


FIGURE 8-12

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.*)

Work Posture

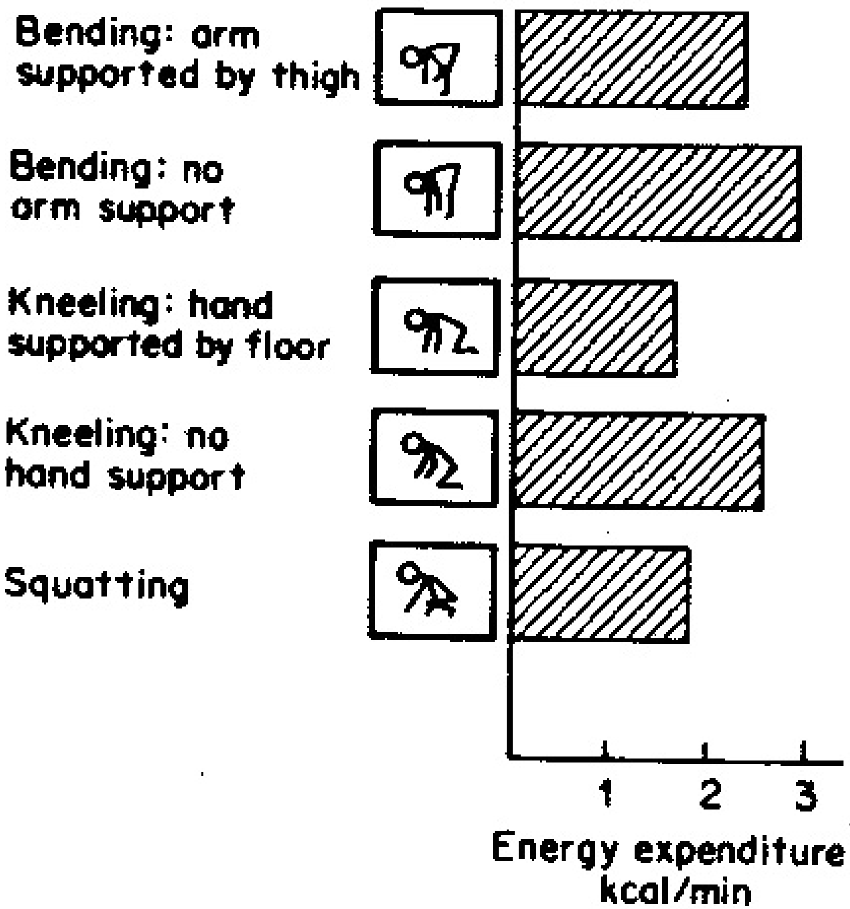


FIGURE 8-13
Human energy expenditures (kilocalories per minute) for five postures used in the task of picking up light objects from ground level. (*Source: Adapted from Vos, 1973, Fig. 5.*)

Work Rate

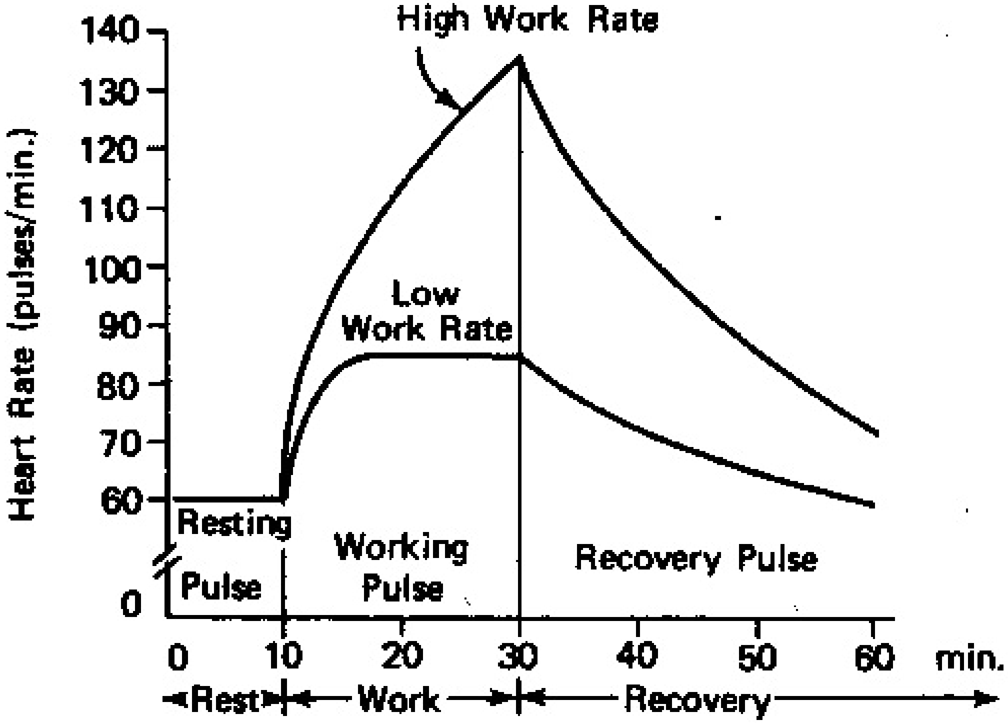
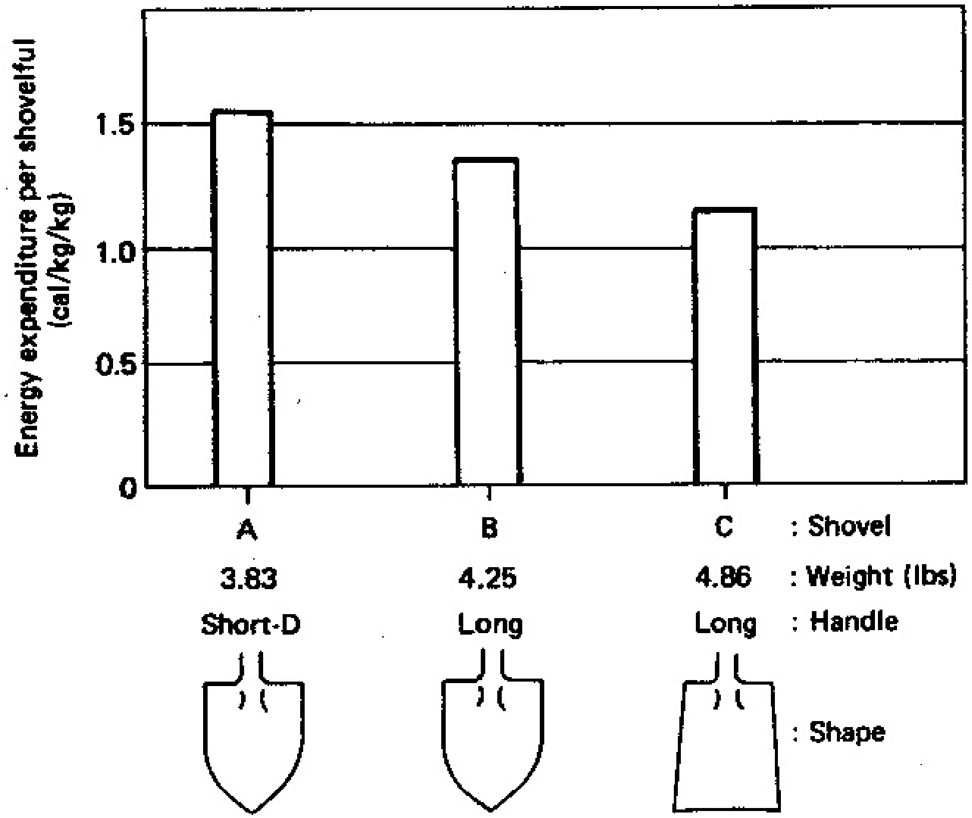


FIGURE 8-14
Heart rate for two different work rates. At the higher work rate the heart rate continues to increase, whereas at the lower work rate the heart rate levels off at a plateau, or steady state. (*From Grandjean, 1988, Fig. 78, p. 95.*)

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
- < 5 kcal / min over 8-h workday – males
- < 3.35 kcal / min over 8-h workday – females
- Max 6.25 kcal / min over 4-h workday – males
- Max 4.2 kcal / min over 4-h workday – males
- 115 beat / min
- 112 beat / min – leg work
- 99 beat / min arm work

Work-Rest Cycles

- Workload > limits
- Compensation (rest)
- Grade of Work & Duration
  - Charts
  - % of work time
  - e.g. very heavy task for 10 min
    - 80% rest = 8 min

Work-Rest Cycles

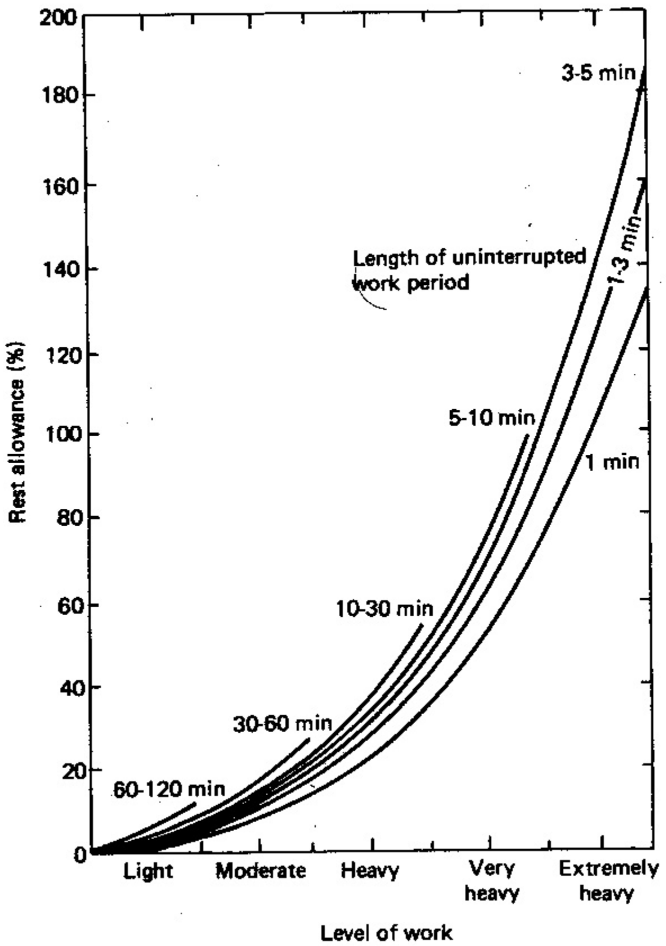


FIGURE 8-16
Rest allowance (as percent of work time) as a function of level of work and length of uninterrupted work period. Levels of work correspond to the following levels of energy expenditure (kcal/min): light = 1–2.5; moderate = 2.6–3.75; heavy = 3.8–6.0; very heavy = 6.1–10.0; extremely heavy > 10.0. (*Source: Kodak, 1986, Fig. 11-2; based on data from Rohmert, 1973*a,b.)

Work-Rest Cycles

- Work period before rest
  - Shorter work periods with shorter rest periods
  - Better physiological recovery and lower stress level

Work-Rest Cycles

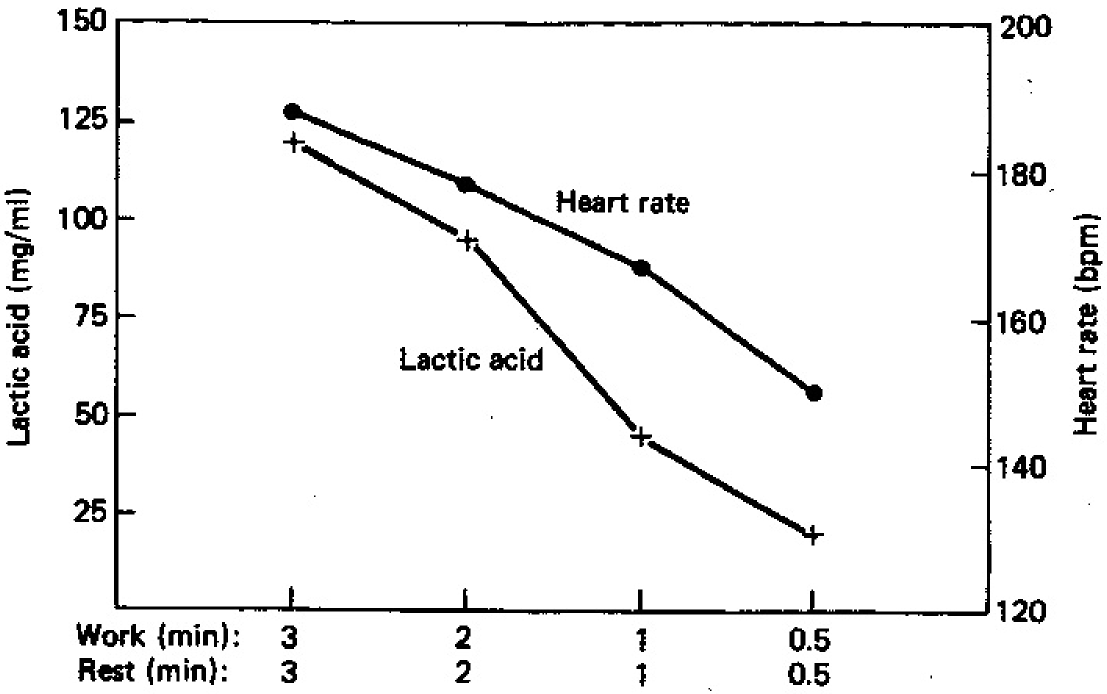


FIGURE 8-17
Effect of length of work and rest period on recovery and physiological strain. In all cases, equal periods of work and rest were performed. The shorter the periods, the greater the recovery and the lower the physiological strain. (*Adapted from Simonson, 1971, Chapter 18. Courtesy of Charles C. Thomas, Publisher, Springfield, IL.*)

Strength & Endurance

- Limiting factors in many tasks and activities
- Endurance:
  - Manifestation of cardiovascular system capability

Strength

- Maximal force muscles can exert isometrically in a single voluntary effort
- Muscle tension is not constant
- Static (isometric – change with time)
- Dynamic (isokinetic – change with movement)

Dynamic Strength

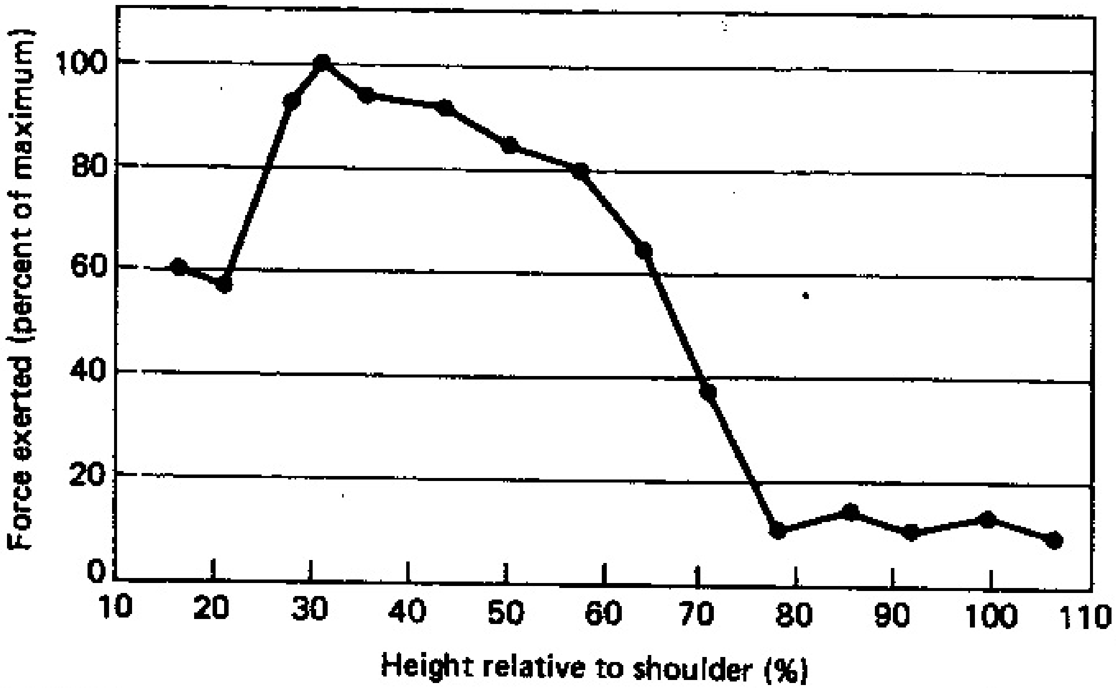
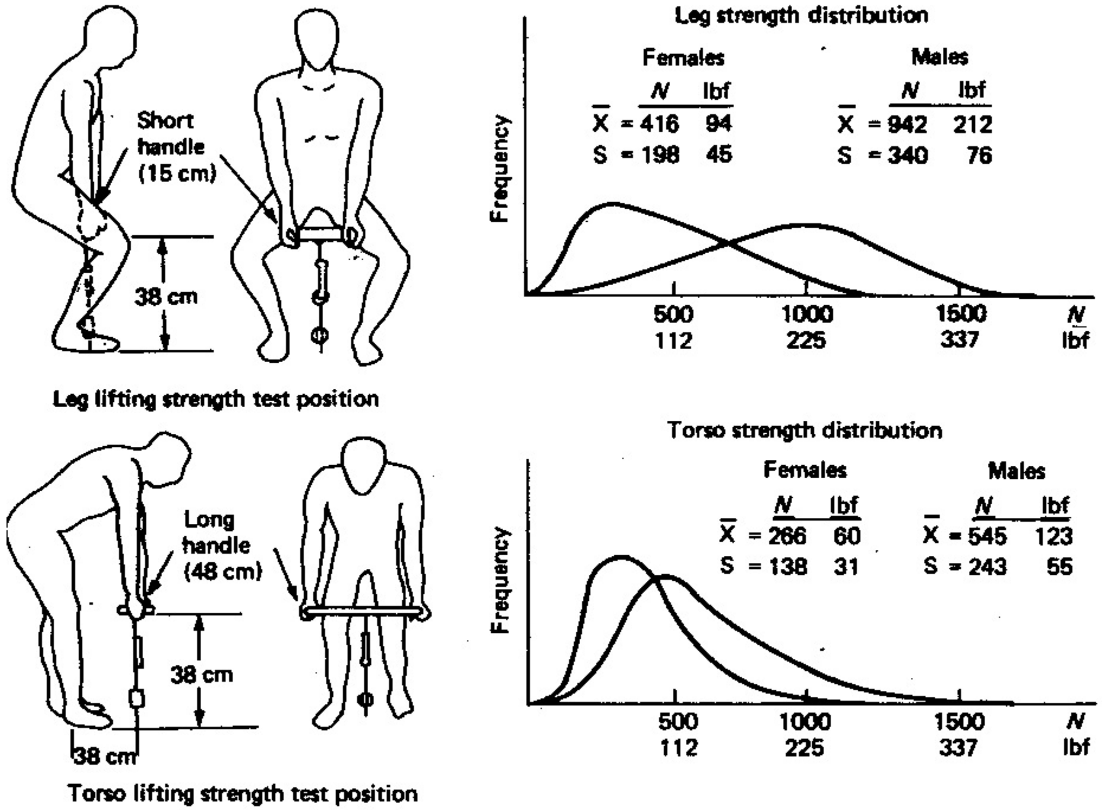


FIGURE 8-18
Dynamic lifting profile for one subject lifting at a velocity of 1 m/s (39 in/s). The values are given as a percentage of shoulder height (55 in; 140 cm) and maximum force exerted (68 lbf; 305 N). (*Source: Adapted from Kodak, 1986, Table 27-1. Reprinted courtesy of Eastman Kodak Co.*)

Static Strength

FIGURE 8-19
Distribution of static strength for males and females illustrating the degree of overlap between the two distributions. (*Source: Chaffin, Herrin, and Keyserling, 1978; as redrawn by Chaffin and Andersson, 1991, Fig. 4.12. © American College of Occupational Medicine.*)



Maximum Static Strength

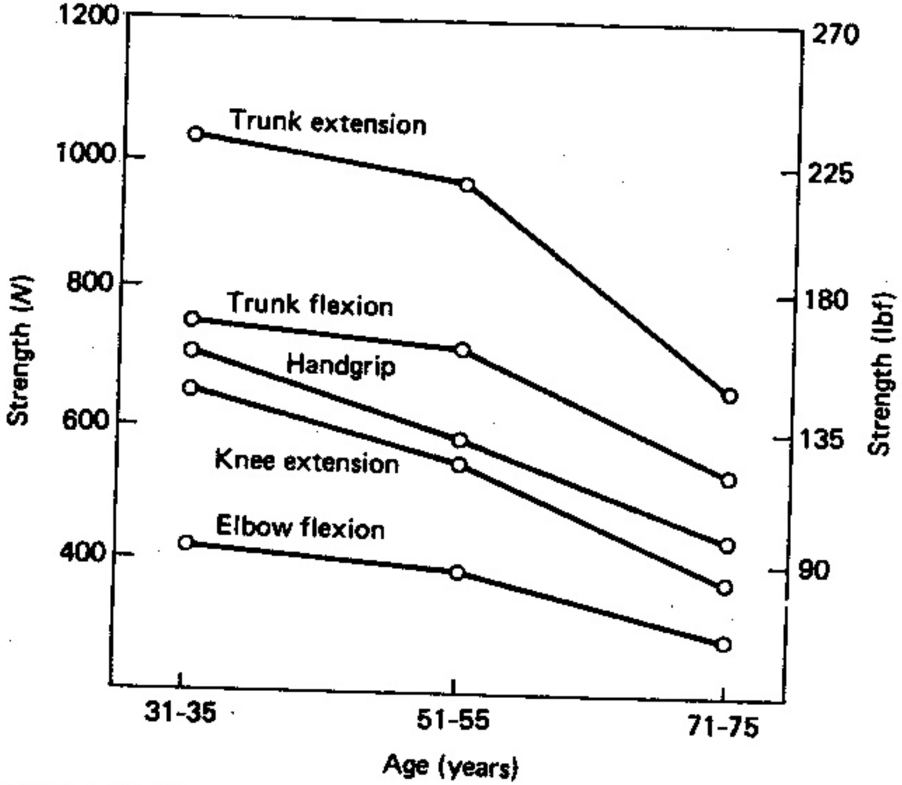
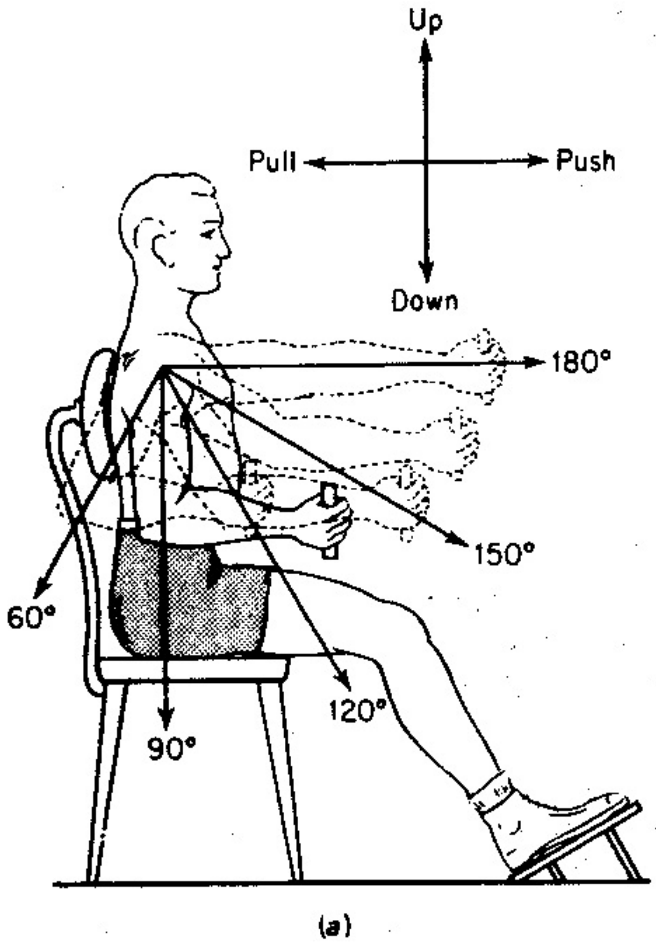


FIGURE 8-20
Maximum isometric strength for five muscle groups as a function of age (cross-sectional study). (*Source: Viitasalo, Era, Leskinen, and Heikkinen, 1985.*)



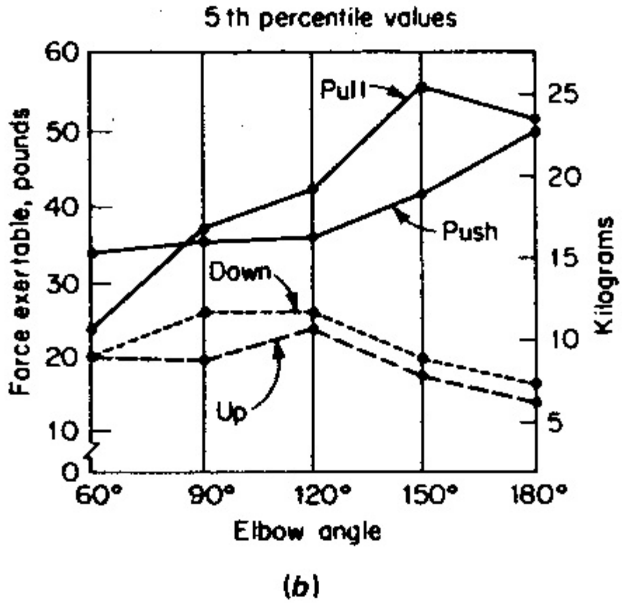


FIGURE 8-21
(*a*) Side view of subjects being tested for strength in executing push, pull, up, and down movements at each of five arm positions. (*b*) Maximum arm strength of 5th percentile of 55 right-handed male subjects. (*Source: Based on data from Hunsicker, 1955.*)

Personal factors Affecting Strength

- Sex
- Age

Examples of Strength Data

Body joint / description	**Female (%ile)**		**Male (%ile)**	
	5	50	50	95
Elbow				
Flexion (90° arm at side)	16	41	77	111
extension (70° arm at side)	9	27	46	67
Knee				
Flexion (135° seated)	22	62	100	157
Extension (120° seated)	52	106	168	318
Torso				
Flexion (100° seated)	49	75	143	216
Extension (100° seated)	71	184	234	503

Endurance

- Maintain a given muscular force

- Repetitive dynamic work
  - Frequency
  - Force

Strength & Endurance

Correlated

Strength & Endurance

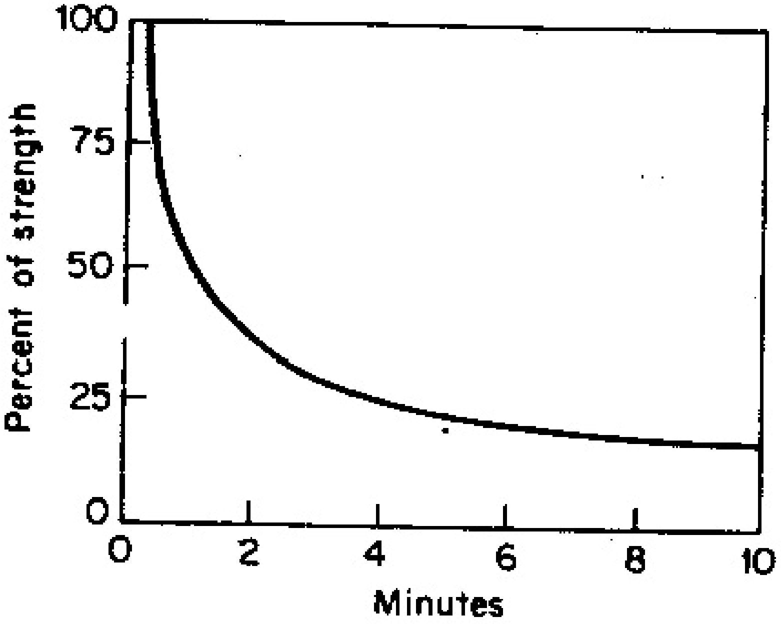


FIGURE 8-22
Endurance time as a function of static force requirements. (*Source: Kroemer, 1970, Fig. 4, as adapted from various sources.*)

Strength & Endurance

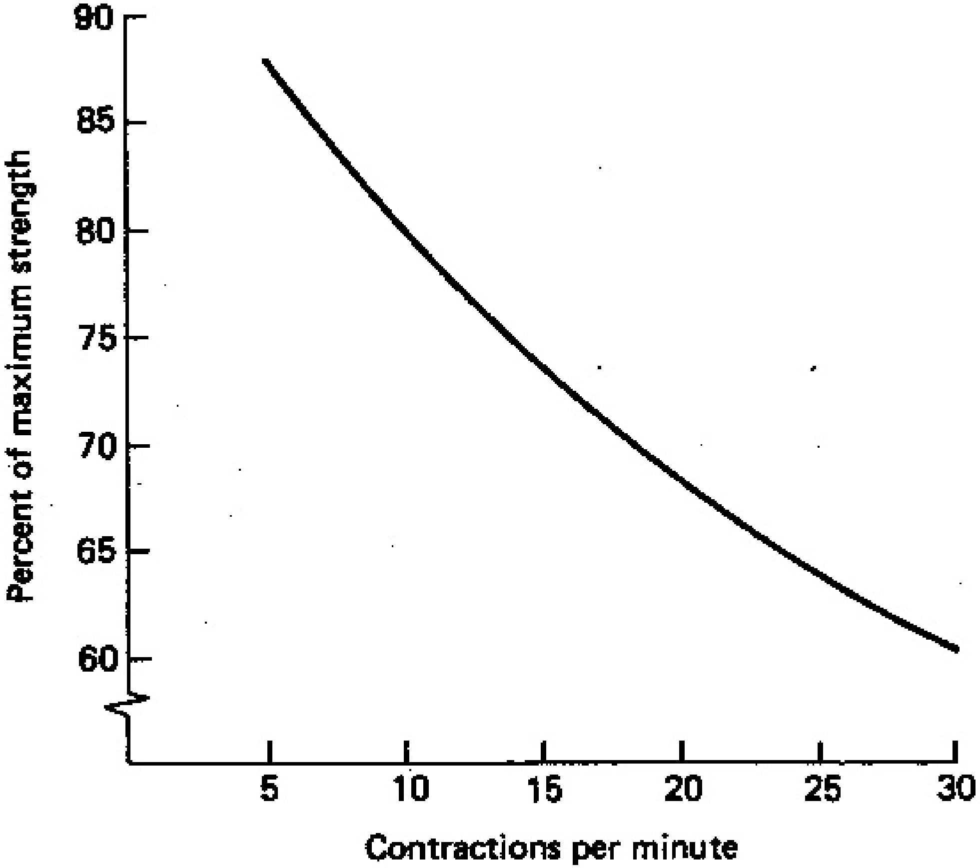


FIGURE 8-23
Percent of maximum isometric strength that can be maintained during rhythmic contractions. Each point is an average for finger, hand, arm, and leg muscles combined. (*Source: Molbech, 1963; as presented by Astrand and Rodahl, 1986, Fig. 3-26. Reproduced with permission of McGraw-Hill.*)

Manual Material Handling (MMH)

- Lifting
- Carrying
- Pushing
- Pulling

Manual Material Handling (MMH)

- Health Effects
  - Lacerations, Bruises, Fractures
  - Cardiovascular strain
  - Muscular fatigue
  - Chronic bronchitis
  - Musculoskeletal injuries
  - Back pain

Approaches to Assessing MMH

- ***Biomechanical***
- ***Physiological***
- ***Psychophysical***
- Each result in different recommended load limits

Biomechanical Approaches

- Human body
  - system of links and connecting joints corresponding to body segments

- Mechanical stress and muscle force

- Models have been developed to determine forces and torques acting on the body during MMH

Biomechanical Approaches

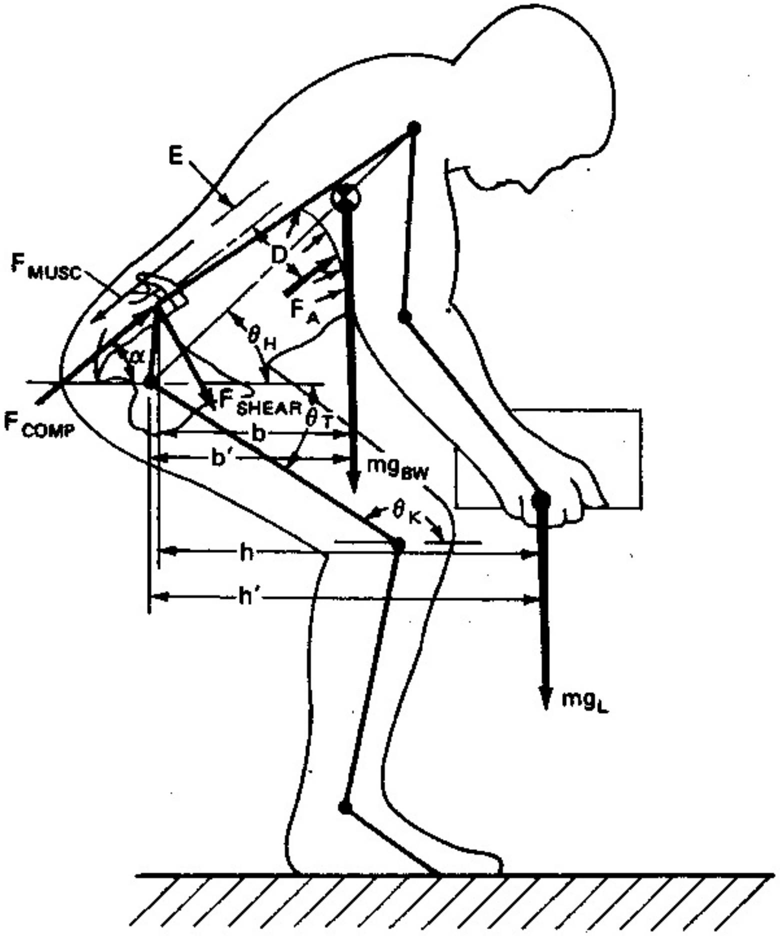


FIGURE 8-24
An example of a simple low-back model of lifting for static coplanar lifting analysis. (*Source: Chaffin and Andersson, 1991, Figure 6.22, as adapted from Chaffin, 1975.*)

Biomechanical Approaches

- Significant forces in the lower back
- Compressive and Shear forces
- Most MMH injuries in the low back area

Physiological Approaches

- Frequent tasks
- Over some duration of time
- 8-hour shift
  - Energy consumption
  - Stresses on the cardiovascular system

Psychophysical Approaches

- Subjective evaluation of perceived biomechanical and physiological stresses
- Max load sustained w/o:
  - Strain or discomfort
  - Unusually tired, weakened, overheated, or out of breath

Psychophysical Approaches

- Appropriate for setting criteria for **MMH** tasks
- Maximum acceptable weigh of load (***MAWL***)
- Validation required
  - Representation of population of workers
  - Repetition
  - Training
  - Reduce visual cues

Lifting Tasks

- Most of the MMH
- Most back injuries
- Variables influence stress during lifting
  - Horizontal position of load
  - Height and range of lift
  - Method of lifting
  - Frequency of lifting
  - Load characteristics
    - *Size, shape, handles, and*
    - *distribution and stability*

Horizontal Position of Load

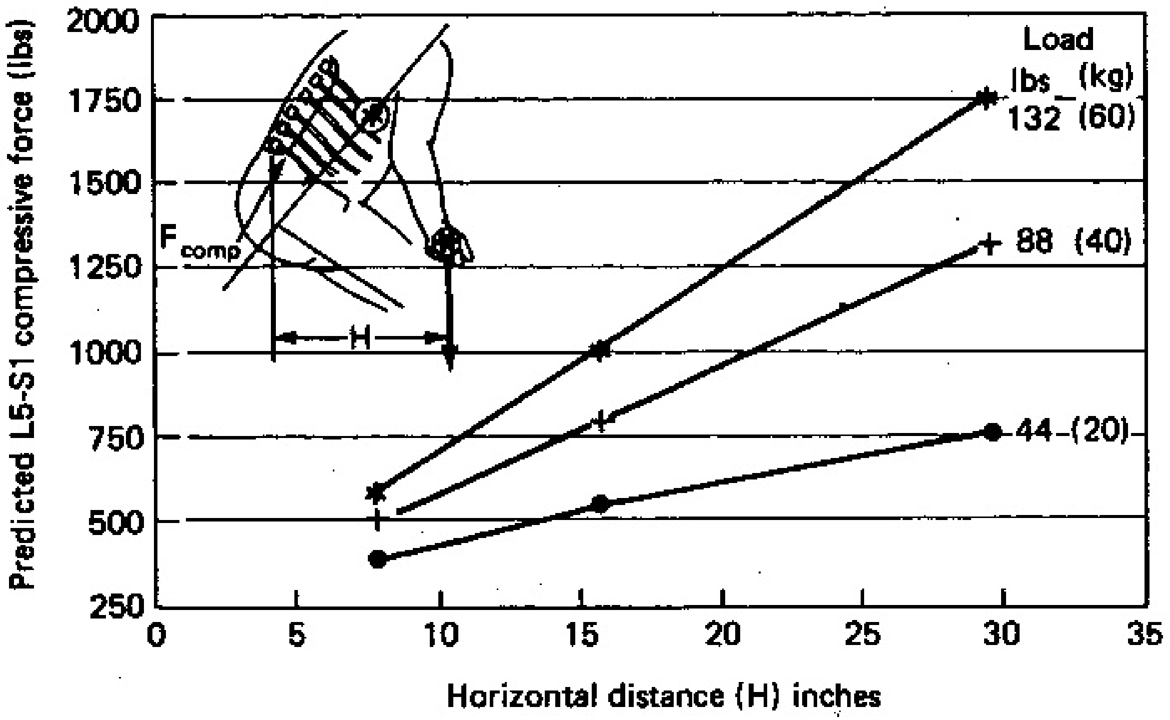


FIGURE 8-25
Effect of weight of load and horizontal distance between the load center of gravity and the L5/S1 disc on the predicted compressive force on the L5/S1 disc. (*Source: Adapted from NIOSH, 1981, Figs. 3.4 and 3.5.*)

Method of Lifting

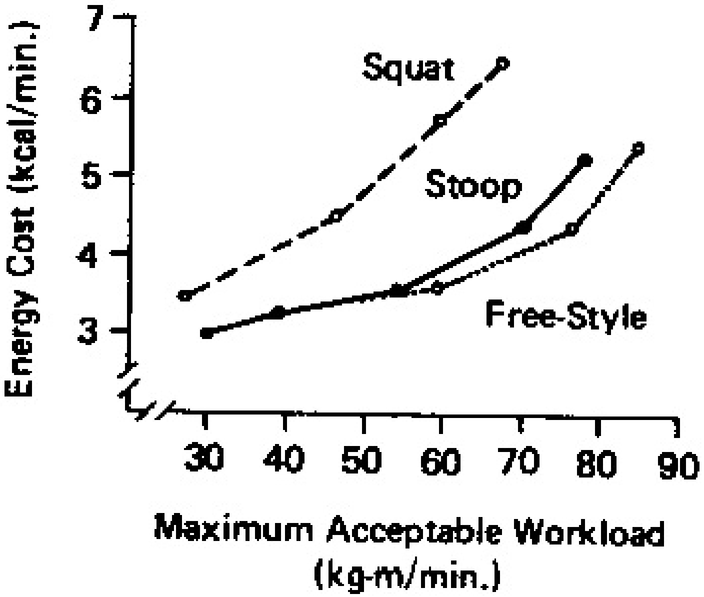
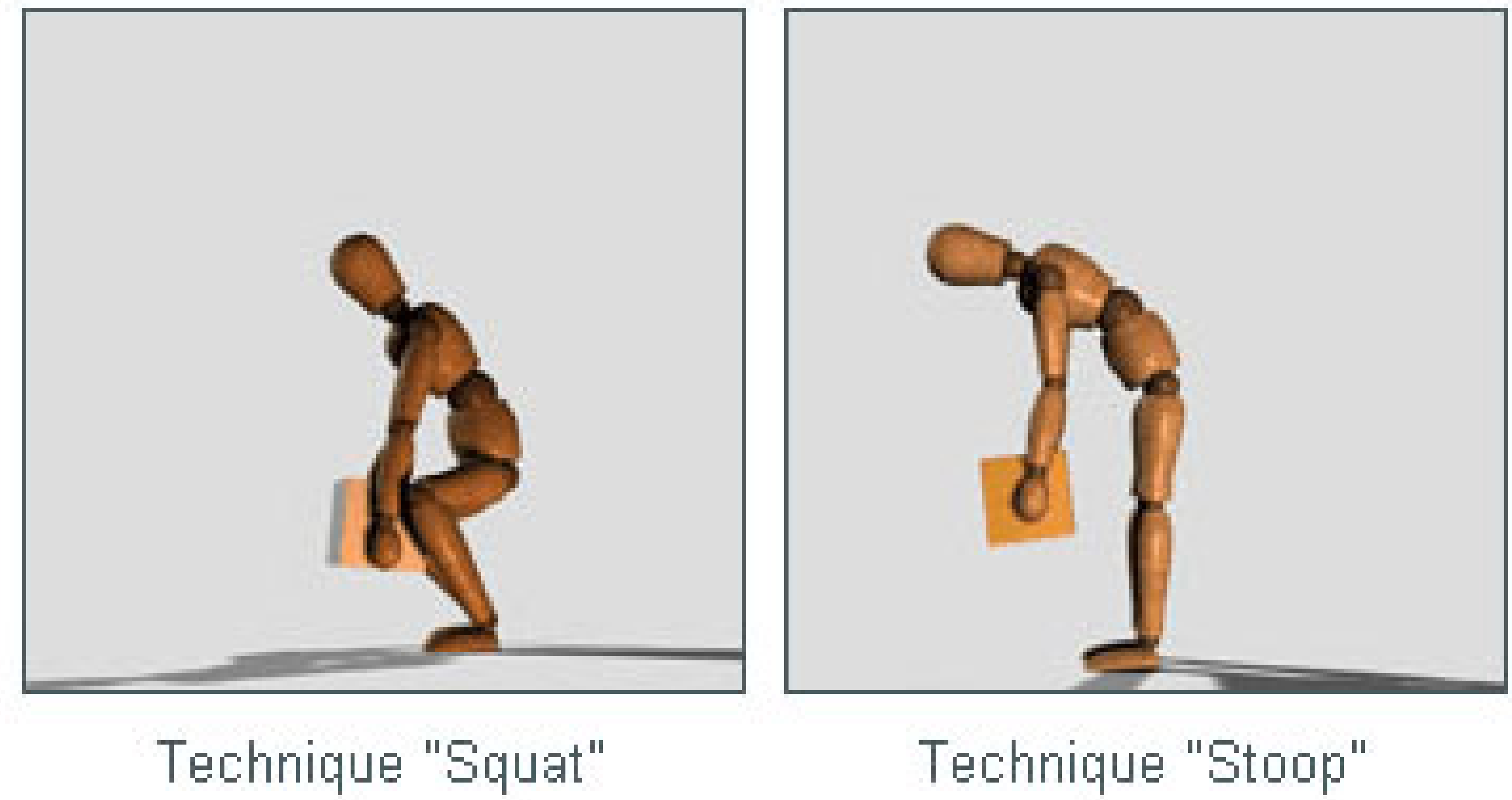


FIGURE 8-26
Energy costs of lifting a load from the floor as related to maximum acceptable workload based on the judgments of the subjects. (*From Garg and Saxena, 1979, Fig. 2, p. 899. Reprinted with permission of American Industrial Hygiene Association Journal.*)

Method of Lifting



Frequency of Lifting

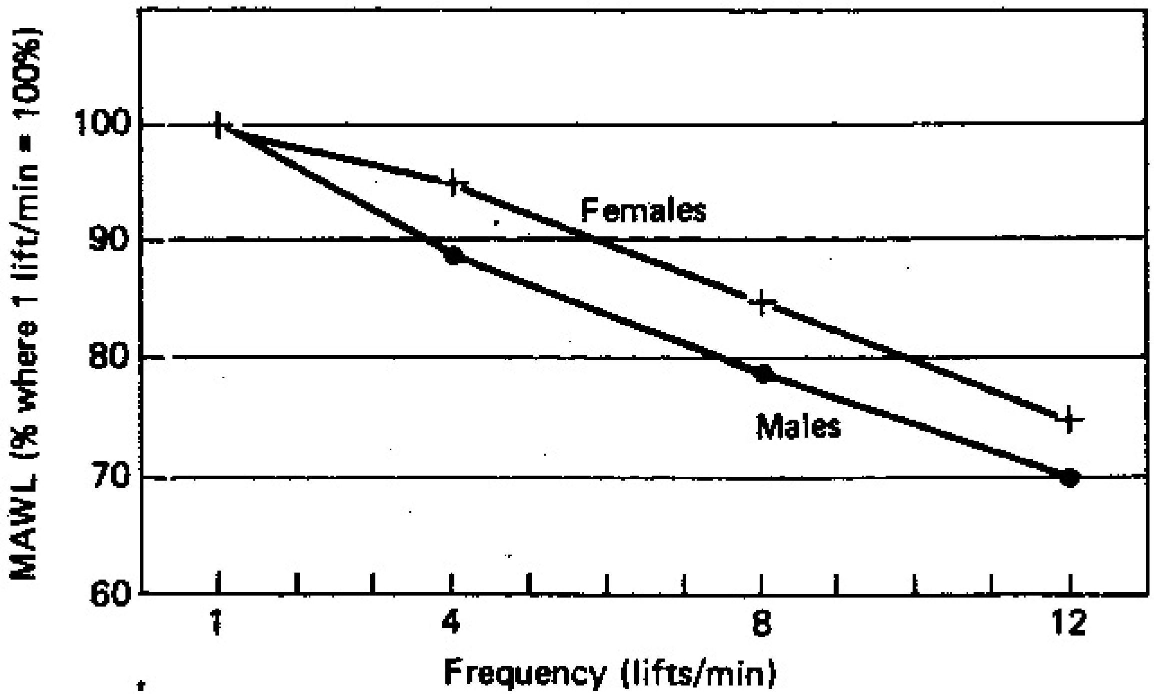


FIGURE 8-27
Relationship between frequency of lifting and maximum acceptable weight of load (MAWL) over an 8-h work day. The values for 1 lift/min were used as the base and equal 100 percent. (*Source: Mital, 1984, Figs. 3 and 4.*)

Frequency of Lifting

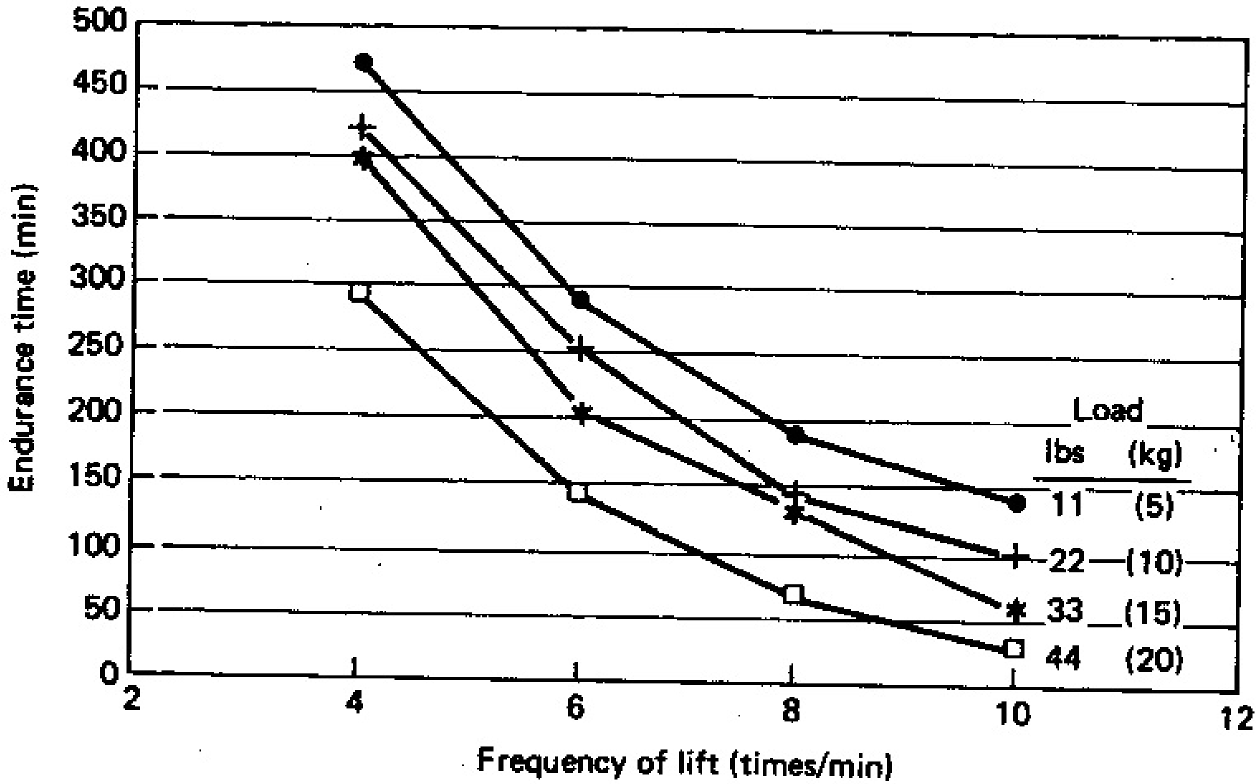


FIGURE 8-28
Endurance time for squat-lifting various loads at various lift frequencies. Lift was from floor to table height. (*Source: Genaidy and Asfour, 1989, Fig. 1.*)

Recommended Limits for MMH Tasks

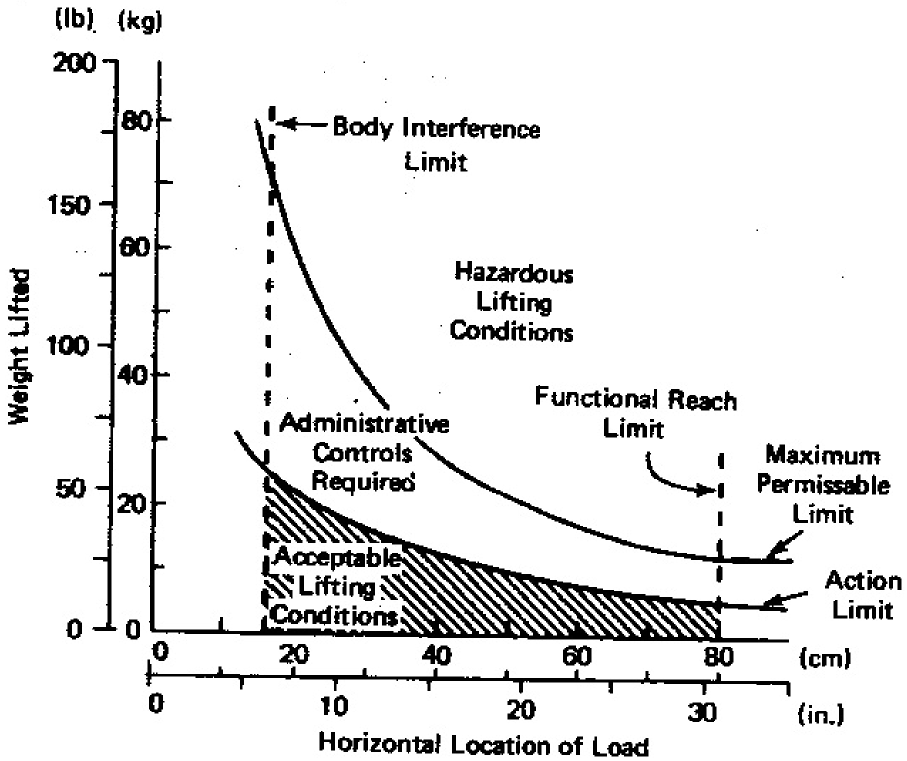
- Biomechanical
- Physiological
- Psychophysical

Biomechanical Recommended Limits

- Based on compressive forces on the low back
  - Action limit (AL)
  - Maximum Permissible limit (MPL)
  - MPL $\leq$ 3 * AL

Biomechanical Recommended Limits

FIGURE 8-32
Levels of risk for lifting tasks as related to horizontal location of load and weight lifted for infrequent lifts from floor to knuckle height. (*This figure is derived from a guideline formula developed by NIOSH, 1981.*)



Physiological Recommended Limits

- 33% of maximum aerobic power (MAP)
- 5 kcal/min

Physiological Recommended Limits

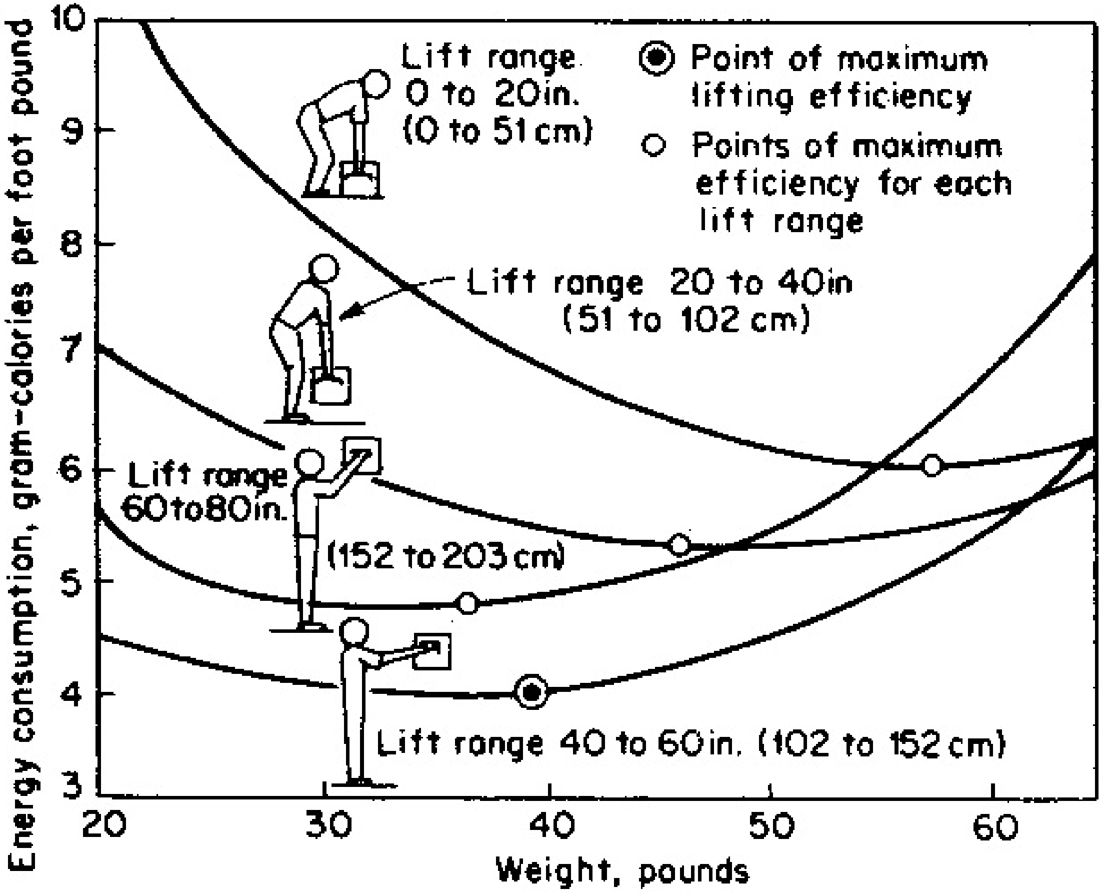


FIGURE 8-33
Energy consumption in lifting per unit of work for various weights and specified lift ranges. The most efficient lifting is with a weight of about 40 lb (18 kg) for a lift range from about 40 to 60 in (102 to 152 cm). (*Source: Frederick, 1959, as presented by Davies, 1972, Fig. 3.*)

Psychophysical Recommended Limits

- MAWL is the recommended load limit for a specific task

Reducing Risk of MMH - Job Design

- Decrease weight
- Use help
- Change activity
- Minimize horizontal distance
- Stack no higher than shoulder
- Keep heavy objects at knuckle height
- Reduce frequency of lifting
- Rest
- Job rotation
- Containers with handles

Reducing Risk of MMH

- Worker selection
  - Pre-employment screening

- Training
  - Controversial