#10 Work Physiology

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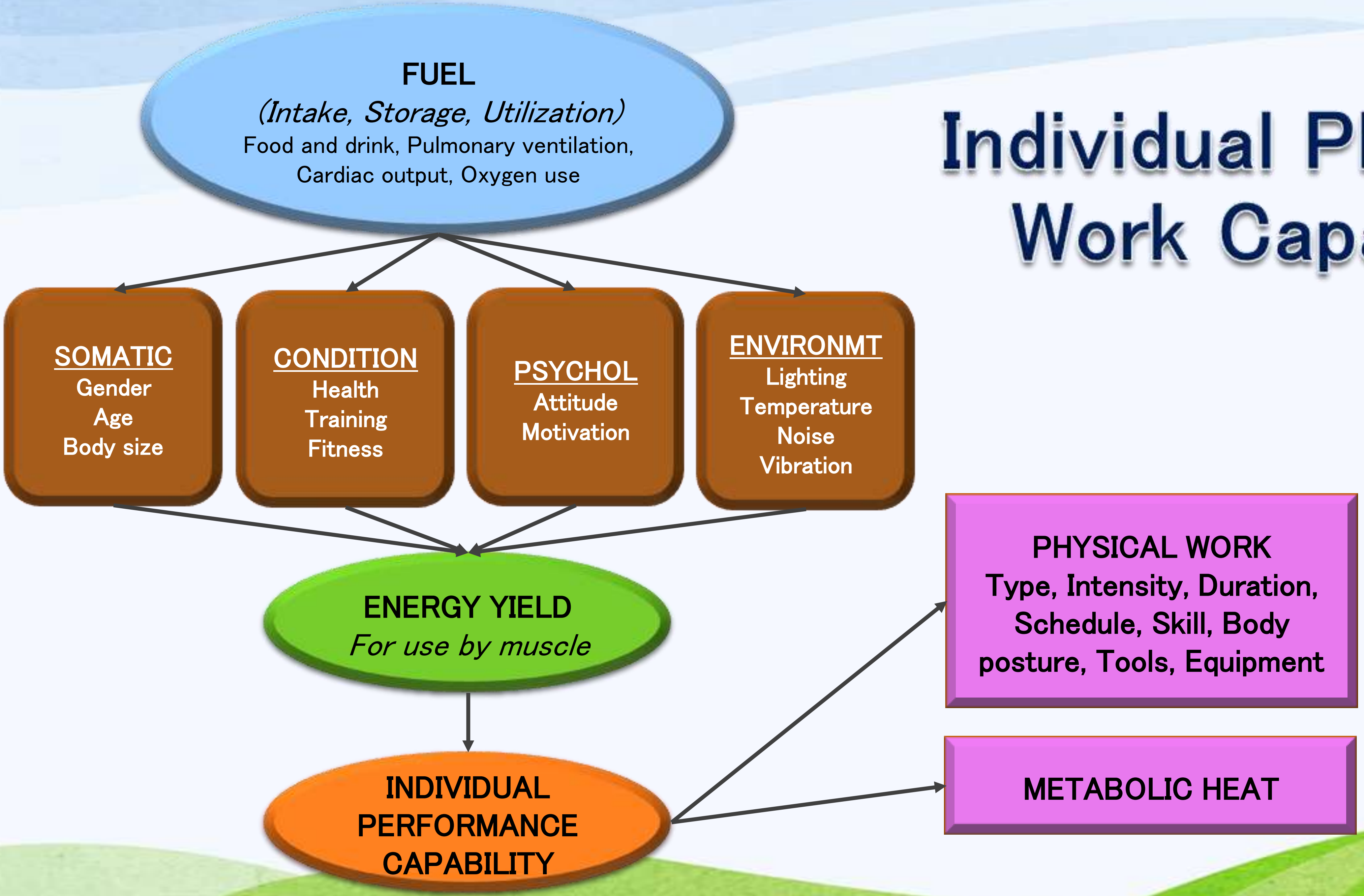
Work Physiology

- This topic is a discussion of **the "energy" side of using muscles** rather than the "mechanics/force" side (biomechanics) extends to metabolism, energy restrictions on work, and fatigue
- ***The capability of the human body for work or exercise depends on its ability to generate varying energy levels over various time periods***.
- These capabilities are determined by :
  - the individual's capacity for energy output (especially physique, health, skill);
  - the muscular and neuromuscular function characteristics (such as muscle strength, coordination of motion, and the like);
  - psychological factors (such as motivation, not a topic of this text); and
  - the thermal environment

Measuring Units for Energy

- The measuring units for energy (exercise, work) are Joules (J) or calories (cal)
  - 4,19 J = 1 cal
  - *(Exactly: 1 J = 1 Nm= 0.2389 cal = 107 ergs = 0.948 × 10—3 BTU = 0.7376 ft lb)*
- For convenience, one often uses the metric kilo joule,
  - 1 kJ = 1,000 J or
  - 1 Cal = 1 kcal = 1.000 cal
- The unit for power is the Watt, 1 W = 1 J/s.

Individual Physical Work Capacity



Resources of Energy (Human Body)

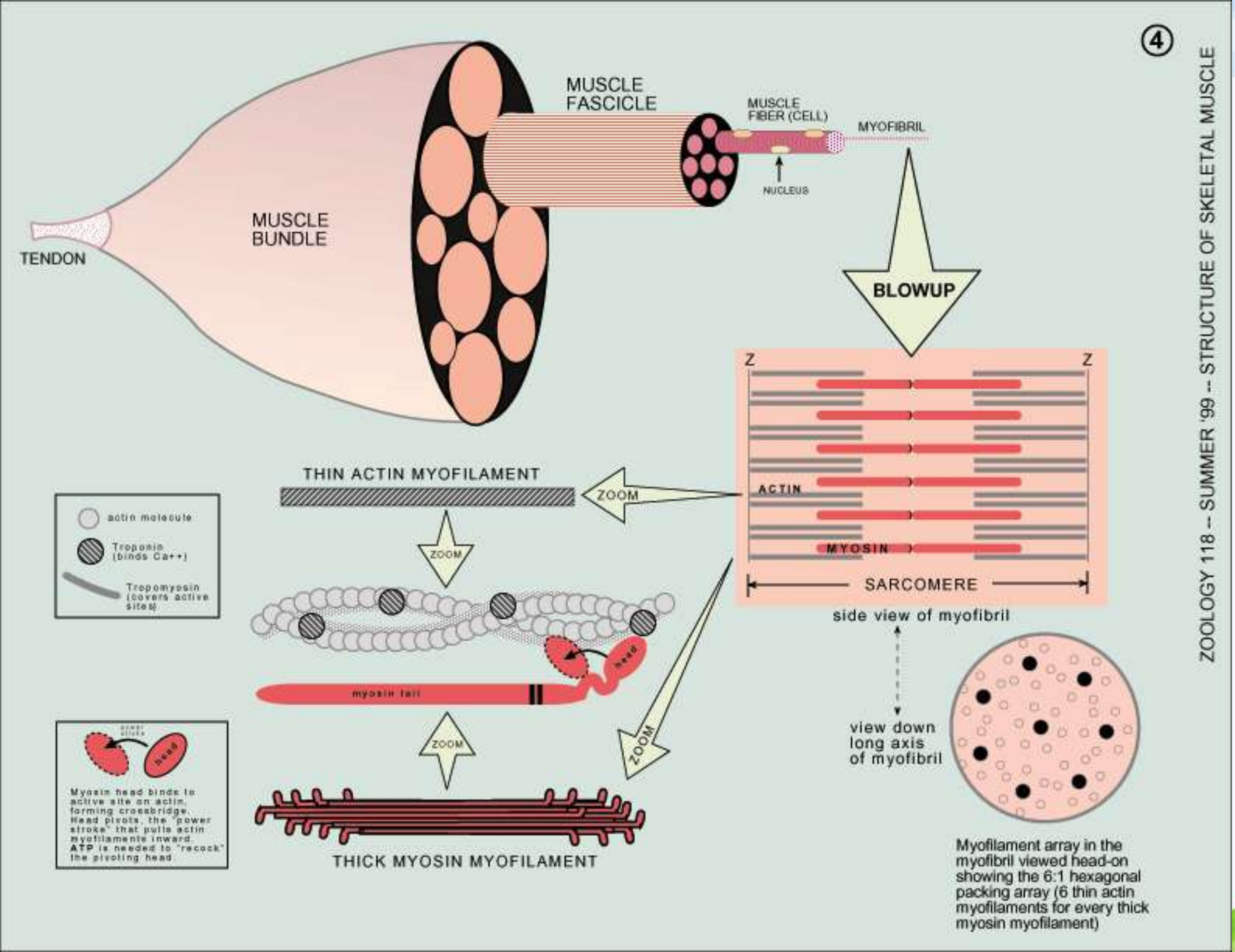
Muscle Structure

Aerobic/ Anaerobic Metabolism

Circulatory System

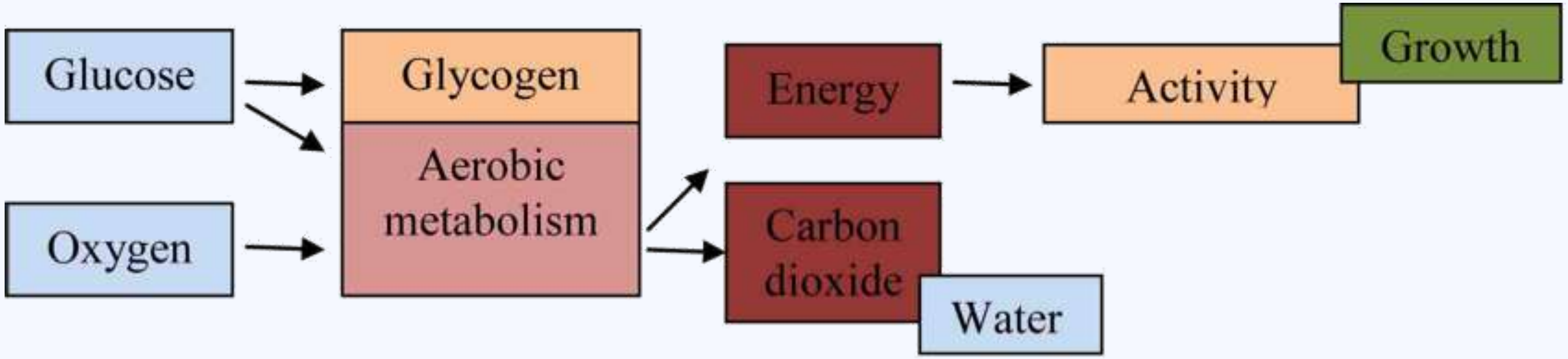
Respiratory System

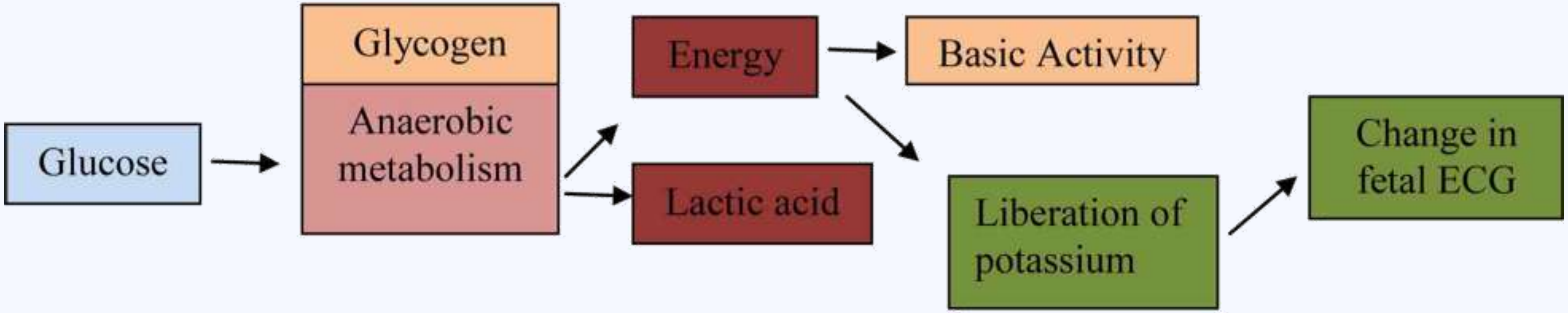
Muscle Structure



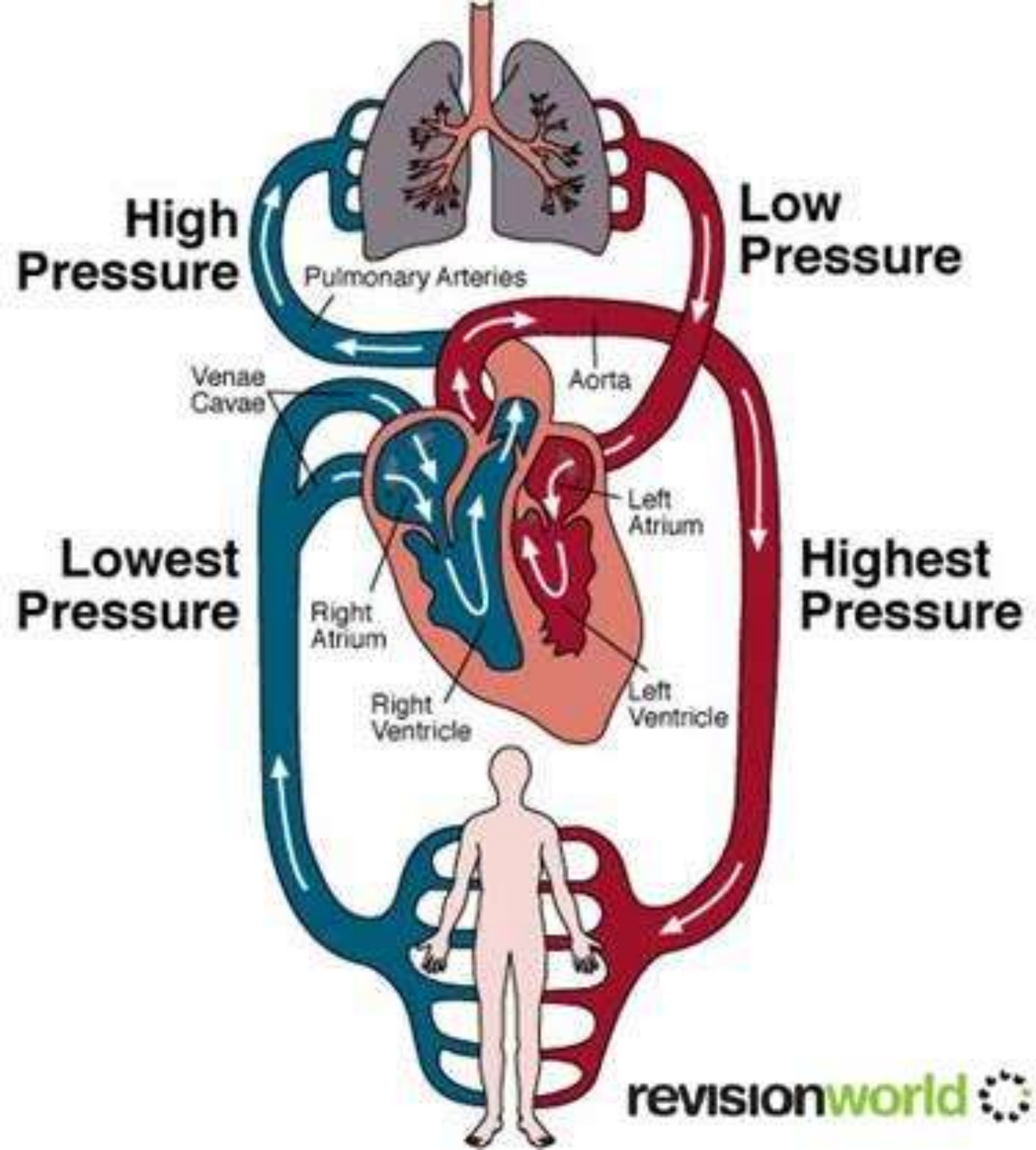
- Two types of proteins actin (thin) and myosin (thick)
  - Actin filaments slide over myosin filaments to produce the contraction
  - Sliding filament theory of muscle contraction
- Muscle efficiency is only about 20%, the rest is lost as heat

Aerobic and Anaerobic Metabolism





- Short term work capacity (aerobic)
  - About 15kcal/min for men
  - About 10 kcal/min women
- Long term work capacity (anaerobic)
  - Suggested not over 1/3 of short term for 8 hrs
  - Higher than this causes fatigue

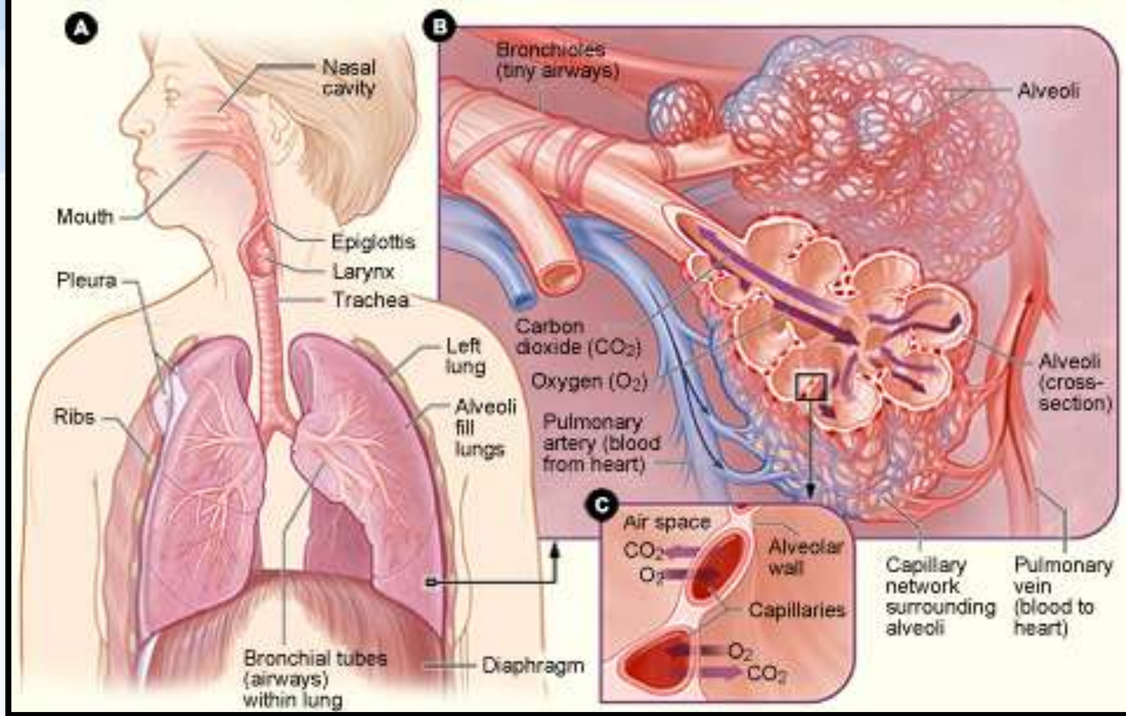


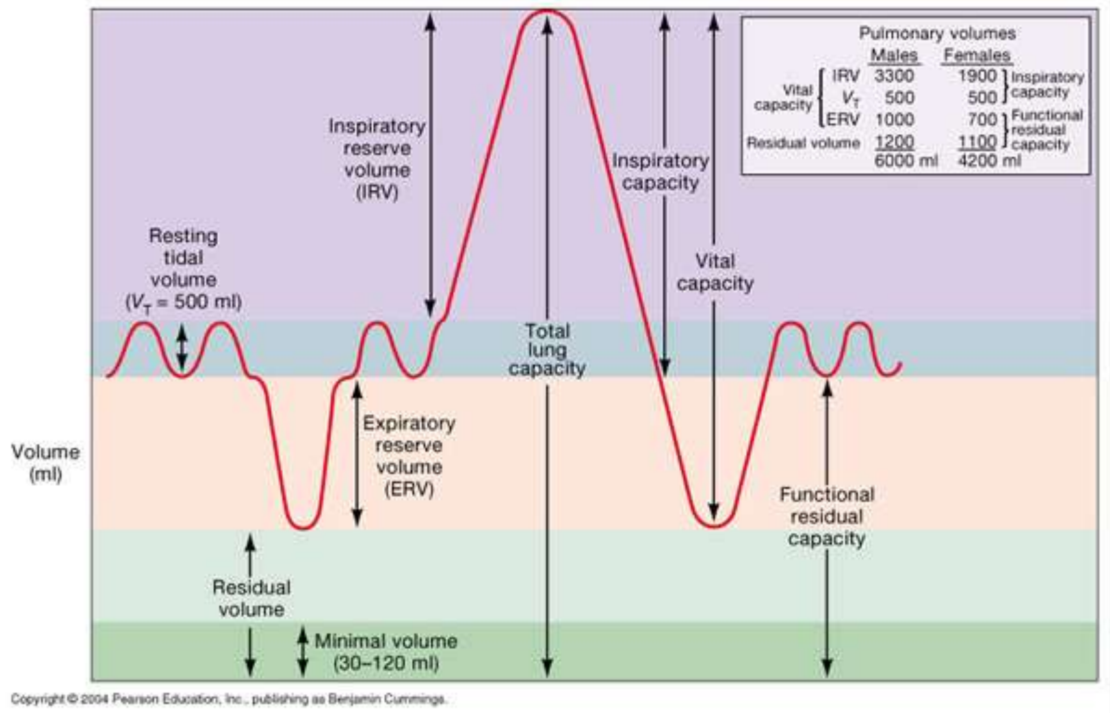
Circulatory System

- Blood delivers nutrients and O_2 to the muscles, carries away CO_2 and waste products
  - Heart – pressure generating blood pump
  - Lungs – site of O_2 and CO_2 exchange
- Cardiac output (Q) : flow rate of blood through the heart
  - **Q=HR x SV**
    - Heart rate: beats per minute
    - Stroke volume: litres of blood per beat
  - **Q values based on activity**
    - 5L/min resting
    - 15L/min moderate work
    - 25L/min heavy work

Respiratory System

- Air exchange system
- Measures :
  - **Tidal volume**: amount of air breathed per breath
    - 0.5L → resting
    - 2L → heavy work
  - **Minute Ventilation** : amount of air per minute
    - tidal volume x frequency
- Body increases tidal volume first, then breathing frequency





Metabolic Requirements

Basal Metabolic Rate

- A minimal amount of energy is necessary to keep the body functioning even if it does no activities.
- Around 1600–1800 kcal/day
- Varies with gender, age, weight

Resting Metabolic Rate

- Depending on the given conditions, resting metabolism is around 10–15% higher than basal metabolism.

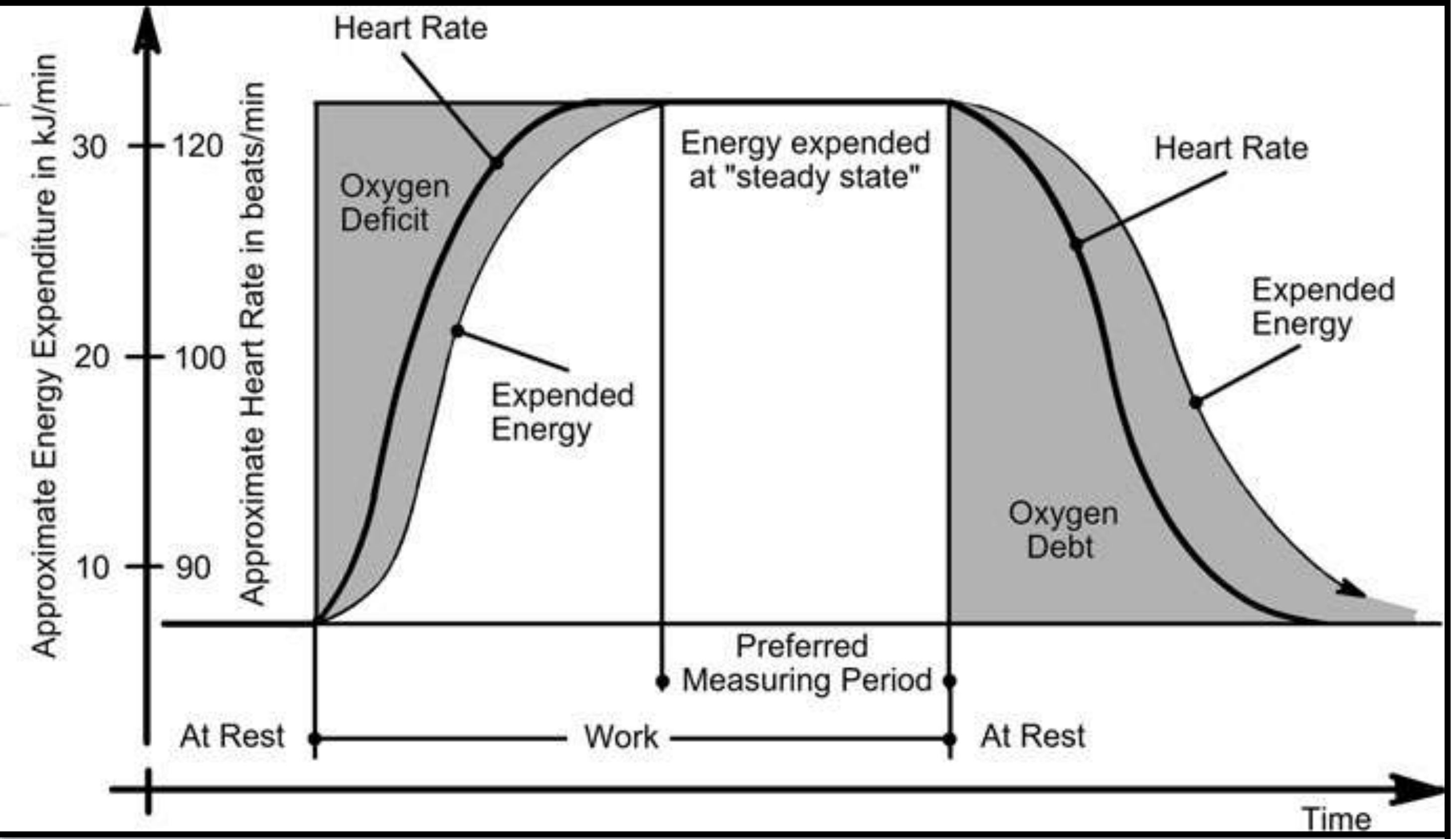
Work Metabolic Rate

- The increase in metabolism from resting to working is called work metabolism: it represents the amount of energy needed to perform the work.

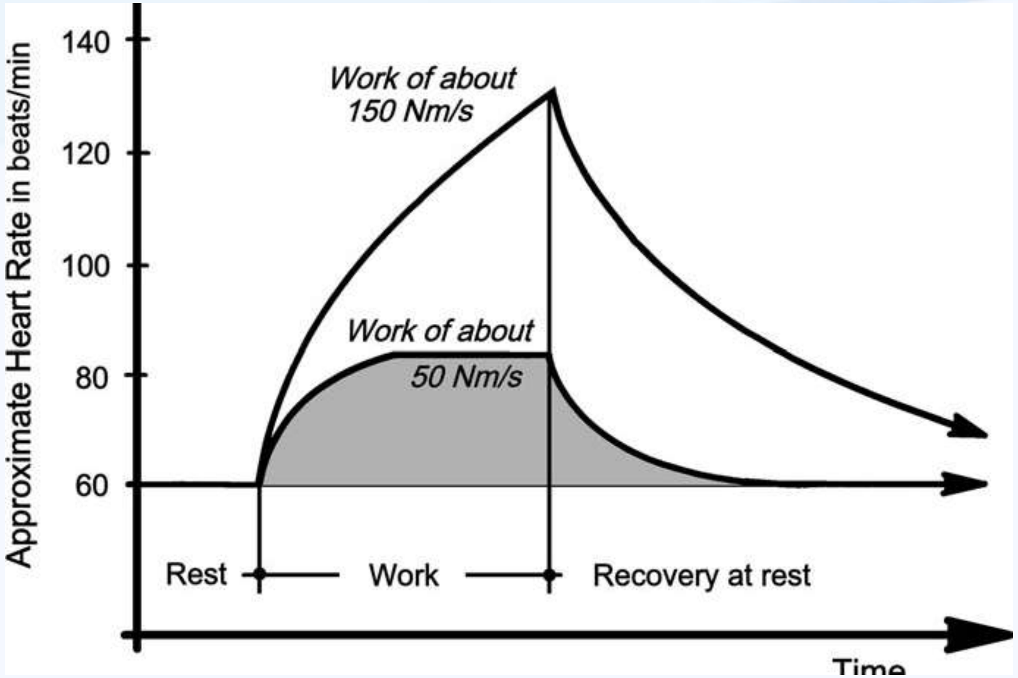
Metabolic rate during work : sum of basal metabolic rate and working metabolic rate

Range : 1,6 to 16 kcal/min

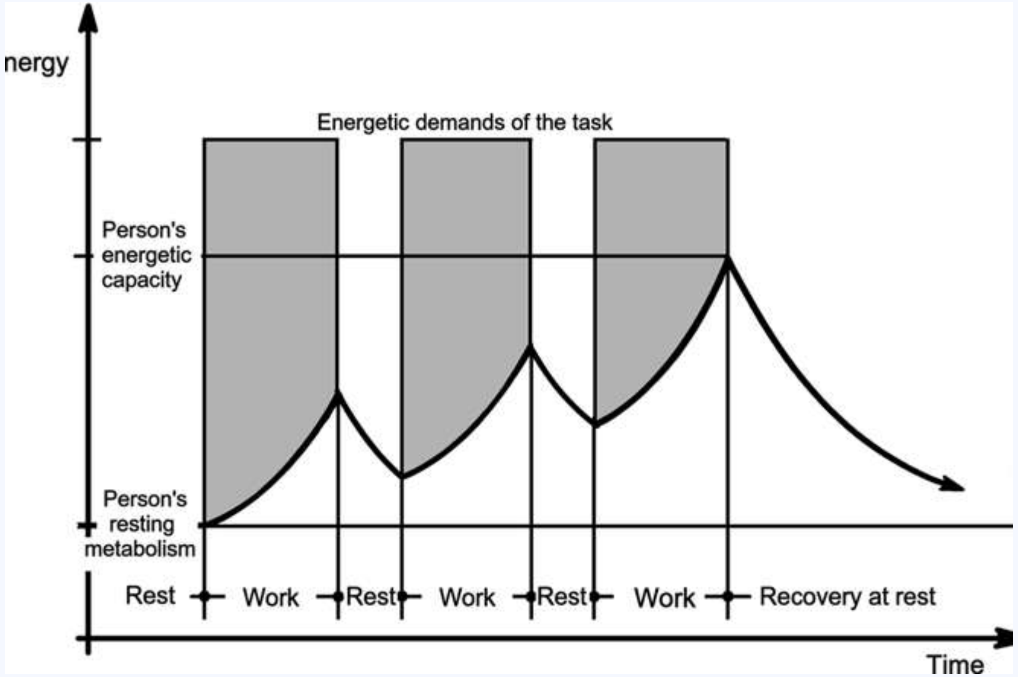
Schematic illustration of energy liberation, energy expenditure, and heart rate at steady state work



- START OF PHYSICAL WORK
  - The actual oxygen uptake lags behind the demand
  - The energy metabolism is almost completely anaerobic because the oxygen supply needs time to meet the demand. (a discrepancy exists between required oxygen and available oxygen)
- STEADY STATE OF PHYSICAL WORK
  - Oxygen intake rises rapidly and finally approaches the level at which it fulfills the oxygen demands of the work.
  - The initial oxygen deficit must be repaid at some time, usually during the following work if it is not overly demanding, or during a rest period.
  - When they maintain this supply level, then the body is at “steady state”.
- END OF PHYSICAL WORK
  - The oxygen demand falls back to its resting level, quickly at first and then leveling off.
  - Still elevated tissue temperature and epinephrine concentration, augmented cardiac and respiratory functions, reconversion of lactate to glycogen and other phenomena cause that, as a rule, the oxygen debt repaid is approximately twice as large as the oxygen deficit incurred.



Heart rate at exhausting work and at steady state work



Metabolic reactions to the attempt of doing work that exceeds one's capacity even with interspersed rest periods

Techniques to Assess Internal Metabolic Capacities

1. Diet and weight observation

- Applied by using balance assumption (there is neither energy storage [when the person gets fatter, more voluminous and heavier] nor use of stored energies (the person getting slimmer).
- Calculate the Body Mass Index, BMI, from weight and stature.

2. Direct calorimetry;

- The amount of heat output from the body provides a direct measure of the person's metabolic rate.
- For the measurement, the room must be small, which limits activities; energy exchange with air, equipment, and walls must be controlled.

3. Indirect calorimetry; and

- Assessment by Oxygen Consumption
- Assessment by Heart Rate

4. Subjective rating of perceived strain.

- Assessment by "rating the perceived exertion" (RPE)

Classification of Work

Classification	Total energy expenditure		Heart rate
	kJ/min	kcal/min	Beats/min
Light work	10	2.5	90 or less
Medium work	20	5	100
Heavy work	30	7.5	120
Very heavy work	40	10	140
Extremely heavy work	50	12.5	160 or more

	Energy expenditure, kcal/day		
	Minimum	Mean	Maximum
Men			
Coal miners	2,970	3,660	4,560
Elderly industrial workers	2,180	2,820	3,710
Elderly Swiss peasants	2,210	3,530	5,000
Farmers	2,450	3,550	4,670
Forestry workers	2,860	3,670	4,600
Laboratory technicians	2,240	2,840	3,820
Steelworkers	2,600	3,280	3,960
University students	2,270	2,930	4,410
Women			
Elderly housewives	1,490	1,990	2,410
Middle-aged housewives	1,760	2,090	2,320
Elderly Swiss peasants	2,200	2,890	3,860
Factory workers	1,970	2,320	2,980
Laboratory technicians	1,340	2,130	2,540
University students	2,090	2,290	2,500

Total Energy Expenditure (per kg body weight) at Various Sports

	Energy expenditure kJ/kg/h
Badminton	53
Bicycling, 9 km/h	15
Bicycling, 16 km/h	27
Bicycling, 21 km/h	40
Cross-country skiing, 9 km/h	38
Cross-country skiing, 15 km/h	80
Ice skating, 21 km/h	41
Jogging, 9 km/h	40
Running, 12 km/h	45
Running, 16 km/h	68
Swimming, breaststroke, 3 km/h	45
Walking, 4 km/h	13
Walking, 7 km/h	25

	kJ/min
Lying down, sitting, standing	
Resting while lying down	0.2
Resting when sitting	0.4
Sitting with light work	2.5
Standing still and relaxed	2.0
Standing with light work	4.0
Walking without load	
Walking on horizontal smooth surface at 2 km/h	7.6
Walking on horizontal smooth surface at 3 km/h	10.8
Walking on horizontal smooth surface at 4 km/h	14.1
Walking on horizontal smooth surface at 5 km/h	18.0
Walking on horizontal smooth surface at 6 km/h	23.9
Walking on horizontal smooth surface at 7 km/h	31.9
Walking on grass at 4 km/h	14.9
Walking in pine forest, smooth surface, at 4 km/h	18 to 20
Walking on plowed heavy soil at 4 km/h	28.4
Walking and carrying on smooth solid horizontal ground	
1 kg on the back at 4 km/h	15.1
30 kg on the back at 4 km/h	23.4
50 kg on the back at 4 km/h	31.0
100 kg on the back at 3 km/h	63.0
Walking downhill on smooth solid ground at 5 km/h	
5° decline	8.1
10° decline	9.9
20° decline	13.1
30° decline	17.1
Walking uphill on smooth solid ground at 2.5 km/h	
10° incline, gaining altitude at 7.2 m/min	
No load	20.6
20 kg on back	25.6
50 kg on back	38.6
16° incline, gaining altitude at 12 m/min	
No load	34.9
20 kg on back	44.1
50 kg on back	67.2
25° incline, gaining altitude at 19.5 m/min	
No load	55.9
20 kg on back	72.2
50 kg on back	113.8

Walking uphill on smooth solid ground at 2.5 km/h
10° incline, gaining altitude at 7.2 m/min
No load 20.6
20 kg on back 25.6
50 kg on back 38.6
16° incline, gaining altitude at 12 m/min
No load 34.9
20 kg on back 44.1
50 kg on back 67.2
25° incline, gaining altitude at 19.5 m/min
No load 55.9
20 kg on back 72.2
50 kg on back 113.8

Climbing stairs or ladder	
Climbing stairs, 35° incline, steps 17.2 cm high	
100 steps/min, gaining altitude at 17.2 m/min, no load	57.5
Climbing ladder, 70° incline, rungs 17 cm apart	
66 steps/min, gaining altitude at 11.2 m/min, no load	33.6

While Rohmert and Rutenfranz claim that, for the same activity, intra- and inter-individual differences in energy consumption are within 10%, a comparison of data presented in various texts shows a much higher percentage of variation, particularly at low activity levels.

Rest Time Requirement

$$R_T = 0 \quad \text{for } K < S$$

$$R_T = \frac{\left(\frac{K}{S} - 1\right) x100 + \frac{T(K-S)}{K-BM}}{2} \quad \text{for } S \leq K < 2S$$

$$R_T = \frac{T(K-S)}{K-BM} x AM \quad \text{for } K \geq 2S$$

K = Energy cost of work (kcal/min)
S = Accepted standard (4kcal/min for female, 5kcal/min for male)
T = total expected duration of task (min)
BM = Basal Metabolism (1.4kcal for female, 1.7kcal for male)
AM = Age Multiplier (see table)

Age Multiplier (AM) for Rest Period	
Age	Multipier
20 – 30	1.00
30 – 40	1.04
40 – 50	1.10
50 – 60	1.20
60 – 65	1.25

Thank you…

Have an enjoy study and see you next week…