MEASURING WORK BY PHYSIOLOGICAL METHODS

IENG 301

FUNDAMENTALS OF WORK STUDY AND ERGONOMICS

Measuring Work by Physiological Methods

- Physiologists demonstrates the validity of using rate of oxygen consumption as the basis for measuring energy expenditure.

- Studies showed that change in heart rate was also a reliable measure of physical activity.

Measuring Work by Physiological Methods

- Physical work results in changes in;
  - Oxygen consumption,
  - Heart rate,
  - Pulmonary ventilation,
  - Body temperature, and
  - Lactic acid concentration in the blood.

- Although some of these factors are only slightly affected by muscular activity, there is a linear correlation between;

  Heart rate – oxygen consumption – total ventilation – the physical work performed by and individual

Measuring Work by Physiological Methods

- Of these three, the first two
  - Heart rate,
  - Oxygen consumption

  are the most widely used for measuring the physiological cost of human work.

- The performance of physical work requires the use of groups of muscles. Some muscles are needed to maintain the body posture while others perform the task

Measuring Work by Physiological Methods

- The physical effort tasks have been classified into three types;
  1. Full body work which utilizes the large muscle groups usually involving 2/3 or 3/4 of the body's total muscles,
  2. Localized muscular work which requires less expenditure of energy because fewer muscle groups are used to perform the task, and
  3. Static muscular work during which the muscles are used to exert a force but no mechanical work is done.

Measuring Work by Physiological Methods

- Static work requires the contraction of muscle groups and can be very demanding.
- The physiological cost of performing a task, then, is affected by the number and type of muscles involved, either to move a member of the body or to control antagonist contraction.

Measuring Work by Physiological Methods

- When a person is at rest, heart rate and the rate of oxygen consumption are at a fairly steady level.

- When the person does muscular work, that is, when changes from a "resting level" to a "working level", both the heart rate and the oxygen consumption increase.

- When work ends, recovery begins, and the heart rate and oxygen consumption return to the original level.

Measuring Work by Physiological Methods

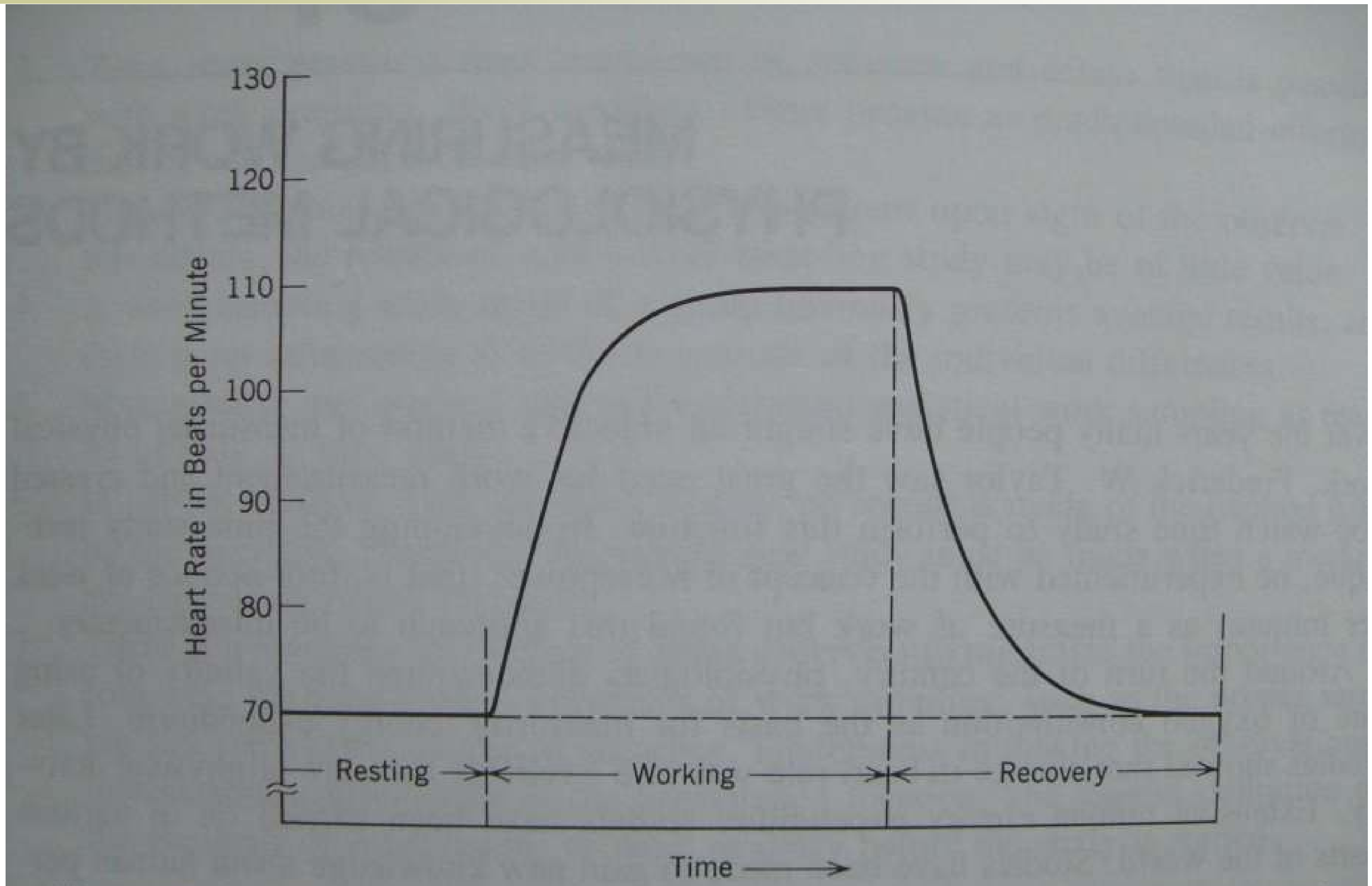


Figure 254 Heart rate in beats per minute before, during, and after physical work.

Heart Rate Measurement

- The increase in heart rate during work may be used as an index of the physiological cost of the job.

- Also the rate of recovery immediately after work stops can be utilized in some cases in evaluating physiological cost.

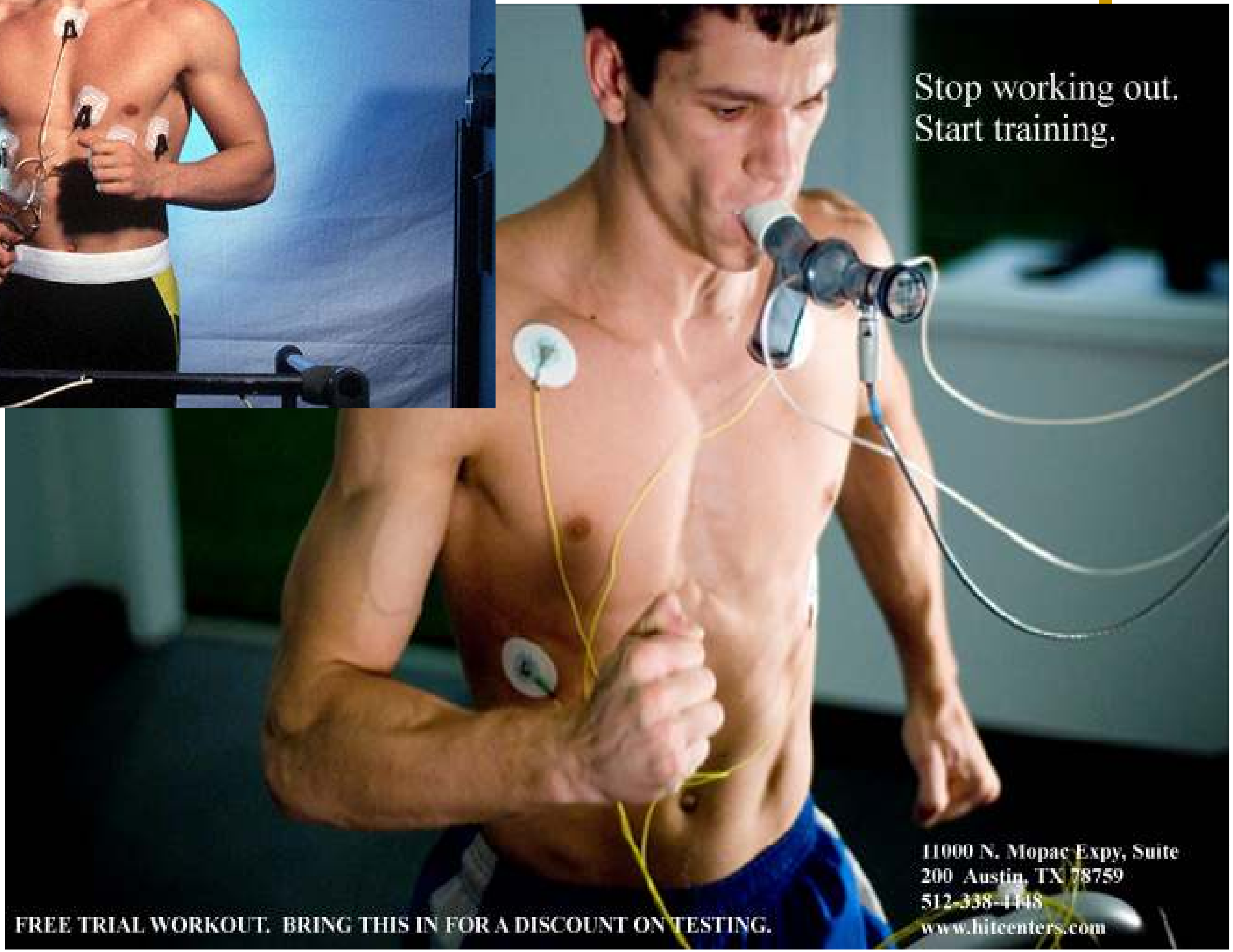
Heart Rate Measurement

- The total physiological cost of a task consists not only of the energy expenditure during work but also the energy expenditure above the resting rate during the recovery period, that is, until recovery is complete.

Heart Rate Measurement

- Each time heart beats, a small electric potential is generated.
- By placing electrodes on either side of the chest, this potential can be picked up and transmitted by wire or by radio transmitter to a receiver.
- There the individual heart beat can be counted directly, or by means of cardiotachometer the impulsives can be converted into heart rate, that is, heart beats per minute.

Figure 255 Apparatus for measuring heart beat and oxygen consumption. *A*, transmitter for telemetering heart beats; *B*, respirometer for measuring volume of exhaled air; *C*, rubber football bladder for collecting random sample of exhaled air.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Heart Rate Measurement

- Heart beat signals can also be obtained by means of an ear lobe unit.
- This apparatus consists of a photo duodiode placed behind the ear and illuminated by a light source mounted on the other side of the ear.
- The opacity (not letting the light through) of the ear lobe changes as the blood surges through the ear with each heart beat.
- The impulse created by each heart beat can be transmitted by wire or radio transmitter and recorded.
- Information concerning rate of recovery also cen be obtained simply by usin a stethoscope and stop watch.

Portable Heart Rate Recorder

- A compact, lightweight, two-lead heart rate recorder which records signals up to 26 hours can be worn by the worker.
- The units has a synchronous motor drive, integrated circuitry, and a rechargeable battery pack.
- An event marker button, when depressed by the worker, records an event mark on the tape for precise time/event correlation.

Portable Heart Rate Recorder

- An autmatic tape scanning system, caled Electrocardioscanner, permits the recordings to be played back at real time recorded speed, or at rapid speeds of 30, 60 or 120 times real time.
- All tape scanning, summarization, and real time documentation is automatic.
- Heart rate is shown as a trend line on an oscilloscope and is automatically printed on a summary trend chart.

Metabolism

- It may be defined as the conversion of foodstuffs into mechanical work and heat.

- To be useful to the body, the foodstuff is converted into a high-energy compound – **Adenosine Triphosphate (ATP)**, which serves as a fuel transport mechanism. It can release chemical energy to fuel internal work in the various body organs.

Metabolism

- ATP conversion process is about 50% efficient, so that half of the total food energy is lost as heat before it can be used.
- At most 25% of the energy that enters the body in the form of foof can be used for muscular work.

Metabolism

- Maintaining the basic body function at rest requires about 1200 kcal/day. This is known as the Basic Metabolic Rate (BMR).

- BMR includes the followinf functions:
  - Heart (215 kcal/day)
  - Brain (360 kcal/day)
  - Kidney (210 kcal/day)
  - Muscles at rest (360 kcal/day)

Metabolism

- On top of maintaining the basic body functions, people usually engage in some minimal activity, ehich is referred to as leisure activity. Together the BMR and leisure activities give an average energy consumption of 2500 kcal/day.

- A total energy requirement of
  - Less than 4000 kcal/day is consiedered moderate,
  - Between 4000 and 4500 kcal/day as heavy,
  - Above 4500 kcal/day as severe.

Metabolism During Work

- Once work has begun, it takes some time for the metabolism to catch up with the energy expenditure of the muscles that are engaged in work.
- In fact, metabolism does not reach a stable level until several minutes after work has begun.
- The amount of time taken depends on how hard the work is, but is typically about 5 minutes.
- Thus, the metabolic activity (given by, oxygen uptake, which is calculated by measuring the volume and oxygen content of exhaled and inhaled air) does not increase suddenly at the onset of work.
- Rather, there is a gradual, smooth increase in oxygen uptake.

Metabolism During Work

- During the initial portion of work, the muscles use a type of energy that does not require oxygen. This type of energy is known as “ANAEROBIC” (without oxygen) metabolism.

- A brief task, such as 100m sprint uses primarily this energy.

Metabolism During Work

- Anaerobic metabolism is inefficient. It uses nearly 20 time more food fuel than does the aerobic process.

- It also produces a waste product (lactic acid) away by blood.

- Eventually,
  - lack of available energy supplies,
  - lack of fel, and
  - accumulation of lactic acid in the muscles

  involved lead to fatigue and cessation of work

Metabolism During Work

- It is generally believed that the accumulation of lactic acide results in aching muscles.

- The same phenomenon is also noted for static work, when static contraction of muscles (e.g. Carrying a suitcase) may produce local muscle fatigue and aching muscles, which may primarily cut off blood circulation.

Metabolism During Work

- As the oxygen uptake increases, the body can use the AEROBIC or oxygen requiring fuel ATP.

- It can be seen that the metabolic rate eventually stabilizes.

- The steady-state level represents the body's aerobic response to the demands of increased workload.

- When the work ceases, the oxygen uptake returns slowly to the resting level prior to work.

- During this slow return after work the oxygen incurred during the onset of work (area A) is repaid (area B).

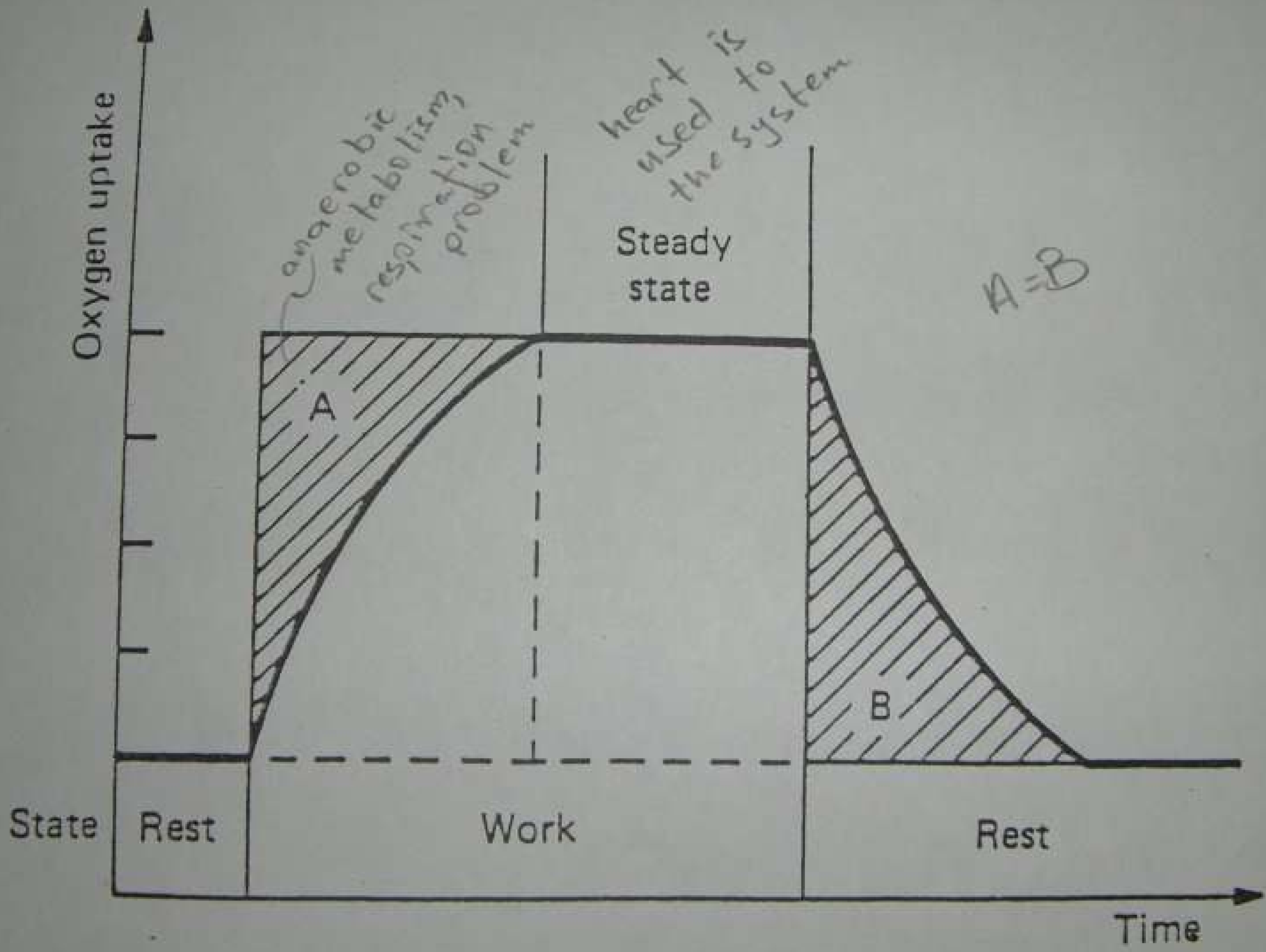
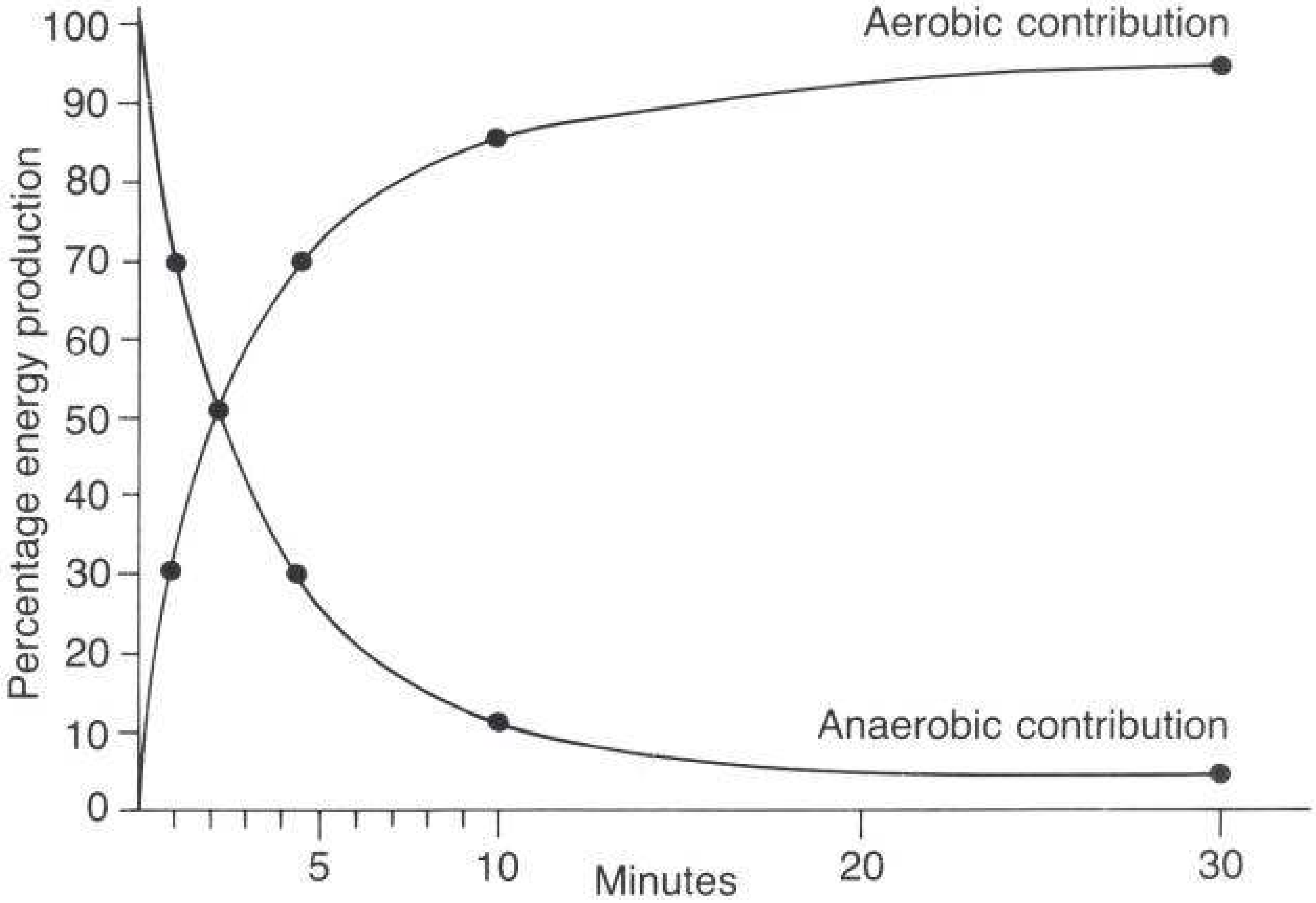


Figure 4.3 Oxygen uptake at the onset of, during and after work. A, oxygen debt; B, repayment of oxygen debt during rest. A = B



Contribution of energy systems to time of movement

Measuring Oxygen Consumption

- Change in the rate of oxygen consumption from the resting level to the working level is also a measure of the physiological cost of work done.

- A person extracts oxygen from the air breathed. In order to measure the oxygen consumed per unit of time, it is necessary to measure the volume of air exhaled and the oxygen content of this air.

- Oxygen consumption may be defined as the volume of oxygen expressed in liters per minute which the indvidual extracts from the air inhaled.

Measuring Oxygen Consumption

- A common method of obtaining thi information is by meands of a portable respirometer.
- The respirometer indicated directly the volume of exhaled air in liters. A sample of the exhaled air is drawn off at random intervals into a rubber football blader, and analysis of its content is made.
- This permits a comparison of the oxygen content of the sample of expired air with that of the air in the room.

Total Metabolic Measurement System

- A total measurement system is available which has integrated transducing, sample handling and data processing component providing printed results.

- The Beckman Metabolic Measurement Cart, designed for making measurements of
  - oxygen consumption,
  - carbon dioxide,
  - expired volume and
  - other related information.

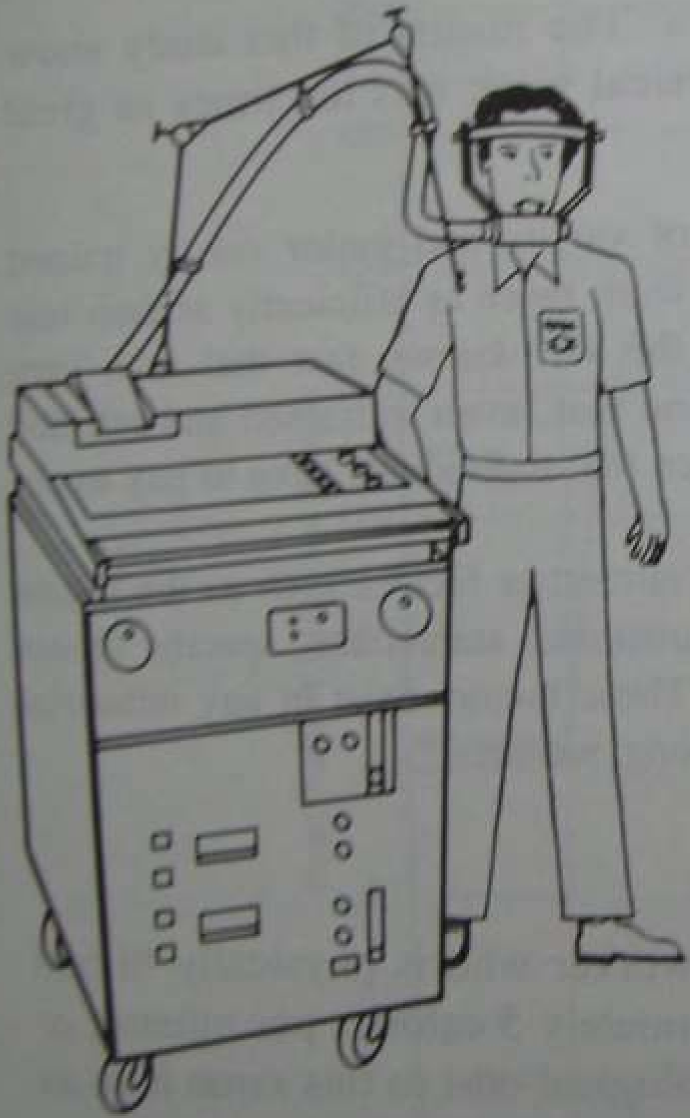


Figure 256 The Beckman Metabolic Measurement Cart is a data processing system. The subject provides exhaled air through a mouthpiece and flexible tube connected to the cart. The cart stores the data, monitors the input, then calculates the answers—measuring oxygen consumption, carbon dioxide, and expired air.

Total Metabolic Measurement System

- The subject provides exhaled air through a mouth piece and a flexible tube connected to the cart.
- The cart is a data processinf system as well as a system of transducers and a sample-handling system.
- A program card inserted in the unit controls its operation.
- The card is read and the functions of the Metabolic Measurement Cart are defined for the test to be performed.

Total Metabolic Measurement System

- The keyboard is used to enter data about the subject.

- The processor then controls the timing, sets the correct opeating conditions, interrogates the analyzers and transducers, stores the data, moniors the input, and then calculates and prints the answers

- It repeats this as often as every 30 seconds.

Individual Differences

- There is a great difference in the ability of individuals to perform muscular work.

- The capacity to withstand the stress of hard physical work is greater in the fit than in the unfit.

Practice – Fitness for Job

- A well-trained male worker who is physically fit and suited to his job might be expected to expend approximately 5 kcalories per minute, or 2400 kclaries per 8-hour day, on his job.

- The physiological cost to this same man as a beginner on the same job would be greater if he attempted to produce the same number of product per day.

- Practice enables the worker to do a job with a lower expenditure of energy. Moreover, the better trained the worker is, the sooner the heart rate will return to the resting level after he stops work.

Physiological Cost of Walking

- Studies of energy expenditure in walking have been made by many different investigators.
- Results of these studies indicate that for speed of 2-4 miles/hour energy expended in kcalories per minute is linearly proportional to the speed of walking in miles per hour.
- Assuming a metabolic sot at the resting state to be 1.2 kcalories per minute, then the relationship can be expressed by the equation

$$C = 1.0V + 1.2$$

C = kcalories/minute

V = speed in miles/hour

Physiological Cost of Walking

- However, energy expenditure is also proportional to body weight.

$$C = 0.047W + 1.02$$

C = kcalories/minute

W = weight (kg)

Use of Physiological Measurements in Work Methods Design

- The objective is to design the work method so that the operator can perform the task 8 hours/day, 5 days/week without undue fatigue.

- Physiological measurements of the worker on the actual job or on a simulated operation can provide useful information pertaining to such problems.

Establishing Time Standards by Physiological Methods

- Physiological measurements can be used to compare the energy cost on a job for which there is a satisfactory time standard, but the comparison should be made for the same person.

- For example, if handling 10-pound cartons at the rate of 12 cartons/minute was considered normal performance, and if energy cost for that worker was 5 kcalories/minute, the answer to the question of what the time standard should be for handling 15-pound cartons under the same conditions might be obained by having the same worker handle 15-pound cartons at various speed, and then selectig the speed that gave an energy cost of 5 kcalories per minute.

- Thus the energy cost of the two jobs would be similar and the time standard could be determined.

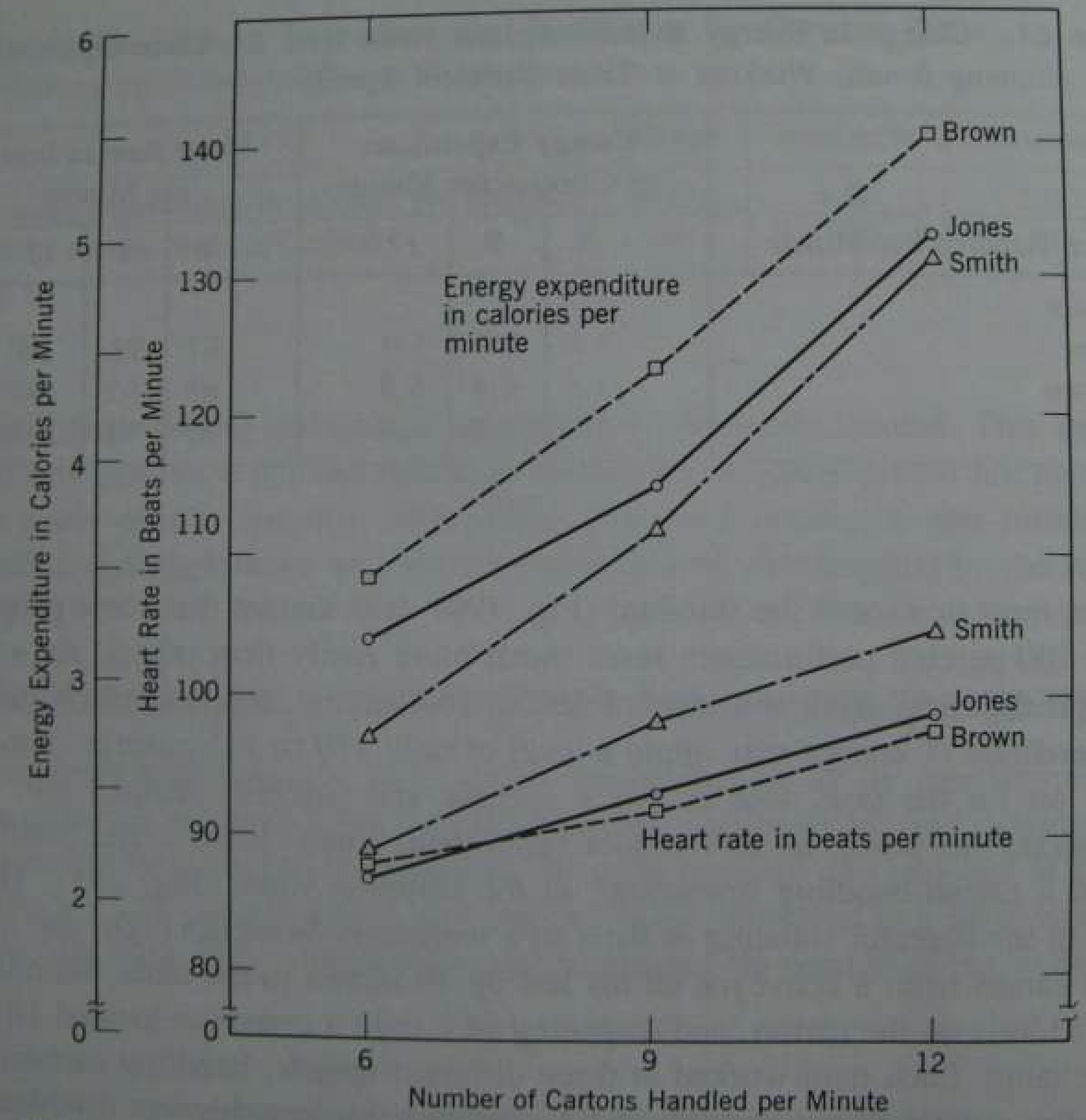


Figure 261 Curves showing change in energy expenditure and heart rate for the three operators in the shipping room, working at three different speeds.

Table 65. Classification of Work Loads in Terms of Physiological Reactions

Work Load	Oxygen Consumption in Liters per Minute	Energy Expenditure in Calories per Minute	Heart Rate During Work in Beats per Minute
Light	0.5–1.0	2.5– 5.0	60–100
Moderate	1.0–1.5	5.0– 7.5	100–125
Heavy	1.5–2.0	7.5–10.0	125–150
Very heavy	2.0–2.5	10.0–12.5	150–175

Table 66. Energy Expenditure Table

Type of Operation	Energy Cost in Calories per Minute
Sitting—idle	1.2
Watch and clock repair	1.6
Clerical work—sitting	1.65
Light assembly work	1.8
Draftsman	1.8
Clerical work—standing	1.90
Tailor hand sewing	2.0
Hand compositor	2.2
Tailor machine sewing	2.6
Sheet metal work	3.0
Punch-press operator	3.8
Tailor pressing suit	4.3
Trimming battery plates	4.4
Straightening lead contact bars	4.6
Pushing wheelbarrow at 2.8 miles per hour with 125-pound load on fairly smooth surface	5.0
Shoveling 18 pounds of sand through a distance of 3 feet with 1.5-foot lift at 12 throws per minute	5.4
Unloading battery boxes from oven	6.8
Pushing wheelbarrow at 2.8 miles per hour with 330-pound load on fairly smooth surface	7.0
Shoveling 18-pound load through a distance of 3 feet with lift up to 3 feet at 12 throws per minute	7.5
Digging ditch in clay soil	8.5
Tending furnace in steel mill	10.2

Establishing Time Standards by Physiological Methods

- Results of research and experience in industry support the following statements as to the acceptable physiological cost of full body muscular work over an 8 hour day:
  - For the average male worker a maximum average energy expenditure of 5 kcalories per minute – a maximum average heart rate of 115 to 120 beats per minute.
  - For the average female worker a maximum average energy expenditure of 4 kcalories per minute – a maximum average heart rate of 115 to 120 beats per minute.

Example

- A 30 year old man of average height (173 cm) and average weight (68 kg) is employed in packaging.
- This task imposes 23 watts (W) of external work.
- His resting metabolic rate just prior to work is about 93 W.
- The steady-state energy expenditure for this task is 209 W.
- Both values can be calculated by measuring his oxygen consumption.

Example

- The increase in oxygen uptake due to the imposed task is:

  209 – 93 = 116 W

- The 23 W of external work therefore imposes 116 W of internal work, and the energy efficiency is;

  23 / 116 = 20% (efficiency = $\frac{\text{external work}}{\text{change in internal work}}$)

Example

- The VO_2 max (volume of maximal oxygen uptake) for this 30-year old man is 3.5 liter per minute.
- The oxygen uptake can be converted directly to work, and 3.5 liter per minute corresponds to 1179 W of work
- Assuming 20% efficiency in energy conversion, this translates to 236 W (1179 x 0.20 = 236) of external work.
- The assembly work therefore corresponds to a 23 / 236 = 9.7% relative load.
- This is much below 25% and is not excessive.

Example

- This calculation example can be expanded by analyzing other individuals with a lower maximal oxygen uptake.

- For example, a 60-year old female has a VO_2 max of 2.2 liter per minute.

- This translates to
  - 134 W (1179/3.5 x 2.2 x 0.20 = 134) of external work and,
  - a relative workload of 17% (23 / 134 x 100 = 17%)

- For an untrained individual with a maximum worload of 25%, this would be on the high side.