Effects of Exercise on the Respiratory System

Editing File

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Special Thanks to Hasan Alsughayir for the Sketch <3

Objectives

01 Explain the respiratory changes in exercise (e.g Oxygen consumption, pulmonary ventilation and VO2 max).

02 Describe the effects of moderate and severe exercise on oxygen consumption, and ventilation volumes.

03 Interpret the effects of exercise on arterial PO2, PCO2 and PH+

04 Define the diffusing capacity of the respiratory membrane, and its typical values at rest, and explain its changes in exercise.

05 Explain the concept of oxygen debt (definition, value, types, significance).

06 Discuss the effects of smoking on pulmonary ventilation in exercise.

07 Discuss the factors stimulate ventilation (hyperventilation) in exercise.

08 Outline the relation between the chemical and nervous Factors in the control of Respiration during exercise.

Male Dr: Abdulrahman Alhowaikan
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Ninja nerd Respiration During Exercise


Respiratory Response To Exercise

Effect of Exercise on Ventilation

01 O2 consumption and CO2 formation can increase as much as 20-fold (It depends on Exercise intensity) during heavy exercise.

02 In the healthy athlete, alveolar ventilation ordinarily increases almost exactly in step with the increased level of oxygen metabolism.

03 The arterial PO2, PCO2, PH all remain almost exactly normal.

442 ;
استهلاك O2 وإنتاج CO2 تزيد مع التمرين لكن ليه PO و PCO2 ثابت وطبيعي ؟ السبب إن الزيادة في استهلاك O2 يقابلها زيادة في alveolar ventilation فا الأكسجين يستهلك ويعوض في نفس الوقت ..

Notice the ↑ O2 consumption as well as ↑ of ventilation.

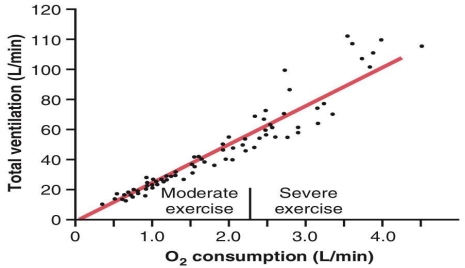


Figure 42-9. Effect of exercise on oxygen consumption and ventilatory rate. *(From Gray JS: Pulmonary Ventilation and Its Physiological Regulation. Springfield, Ill: Charles C Thomas, 1950.)*

Initial drop in arterial PCO2 due to the sudden increase in ventilation.

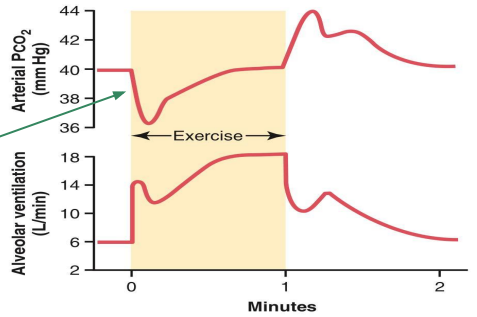


Figure 42-10. Changes in alveolar ventilation (*bottom curve*) and arterial P_{CO_2} (*top curve*) during a 1-minute period of exercise and also after termination of exercise. *(Data from Bainton CR: Effect of speed vs grade and shivering on ventilation in dogs during active exercise. J Appl Physiol 33:778, 1972.)*

VO2 Max and VE

VO2 Max	The maximum rate of oxygen consumption attainable during physical exertion.
VE	The volume of air exhaled from the lung in 1 min.

Other names :

- VO2 max : (maximal oxygen consumption, maximal oxygen uptake, maximal aerobic capacity)
- VE : (minute ventilation)

Oxygen Consumption (VO2) and Pulmonary Ventilation (VE) in Exercise:

01 The normal oxygen consumption (VO2) for a young man at rest is about 250 ml/min.

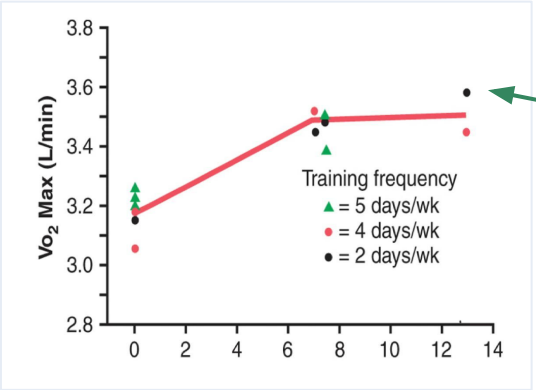
02 The rate of oxygen usage (L/min) under maximal aerobic metabolism (VO2 Max) can be approximately the following average levels:

	ml/min
Untrained average male	3600
Athletically trained average male	4000
Male marathon runner	5100

03 VO2 and VE increase about 20-fold between the resting state and maximal intensity exercise.

Effect of Training on VO2 Max

In the below study*
VO2 Max increased only about 10% by training.



443:
People who trained for only two days had better results.
that's why more doesn't always mean better

Increase in Vo2 Max over a period of 7 to 13 weeks of athletic training.

Other factors that increase the VO2 Max are genetically determined in the form of:

1. Chest sizes in relation to body size
2. The power of respiratory muscles contraction

*Guyton & Hall 14 unit XV chapter 85 page 1079

VO2 Max values

VO2 Max Chart for Men (ml/kg/min)

	Age (years)					
rating	**18-25**	**26-35**	**36-45**	**46-55**	**56-65**	**65+**
excellent	> 60	> 56	> 51	> 45	> 41	> 37
good	52-60	49-56	43-51	39-45	36-41	33-37
above average	47-51	43-48	39-42	36-38	32-35	29-32
average	42-46	40-42	35-38	32-35	30-31	26-28
below average	37-41	35-39	31-34	29-31	26-29	22-25
poor	30-36	30-34	26-30	25-28	22-25	20-21
very poor	< 30	< 30	< 26	< 25	< 22	< 20

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Doctor said:
Don't have to memorize it

Diffusion Capacity of the Respiratory Membrane

01 Defined as the volume of gas that diffuses through the membrane each minute for a pressure difference of 1 mmHg(1 mmHg difference needed to start gas diffusion)

02 Oxygen diffusion capacity is a measure of the rate at which oxygen can diffuse from the pulmonary alveoli into the blood

03 This capacity is expressed in terms of milliliters (mls) of O2 that will diffuse each minute for each millimeter of mercury (mmHg) difference between alveolar PO2 and pulmonary blood PO2.

04 Diffusing capacity for oxygen at rest = 21 ml/min/mmHg

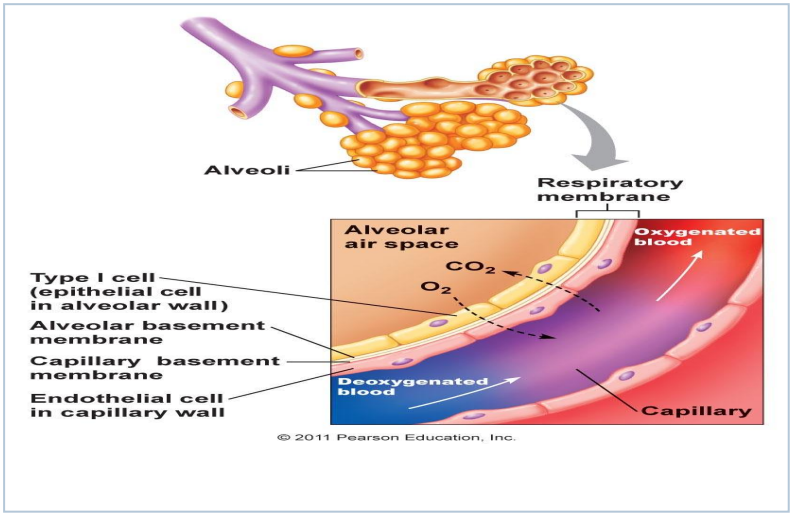
Diffusion Capacity of the Respiratory Membrane

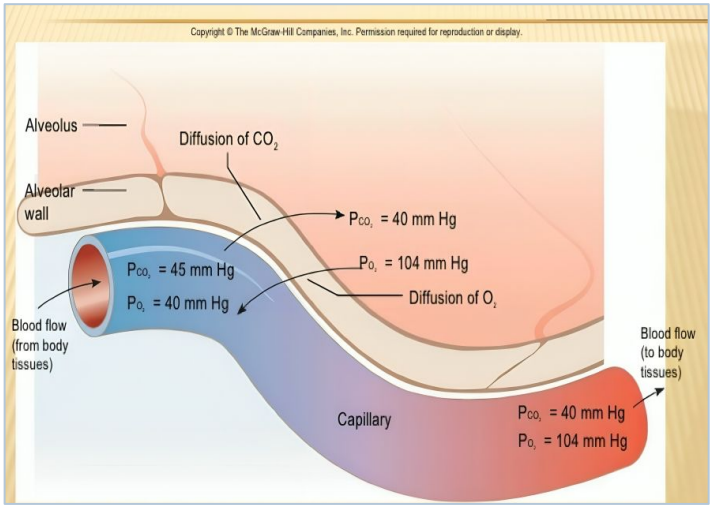
05 **Example:**

If the mean oxygen pressure difference across the respiratory membrane is 11 mmHg. The volume of O2 diffusing through the membrane each minute will be (11x21) = 230 ml.

(enough to supply the O2 needed by the tissues during rest)

- During rest tissues consume 250 ml O2 /min.





Oxygen Diffusing Capacity During Exercise

The diffusing capacity for oxygen increases about three times during exercise (~ 64 ml/mmHg/min).

This is due to :

01 **Increased** number of the open pulmonary capillaries which were dormant, and dilation of the already opened vessels to their maximal. This increases the surface area for gas exchange.

02 **Increased** alveolar ventilation per minute.

03 Better matching of ventilation of the alveoli (V) with the perfusion of the pulmonary capillaries (Q) i.e (V/Q ratio).

- At rest, the blood normally stays in the lung capillaries about three times as long as necessary to cause full oxygenation.
- Therefore, even with shortened time of exposure of the blood to the alveolar air in exercise, the blood is still fully oxygenated or nearly so.

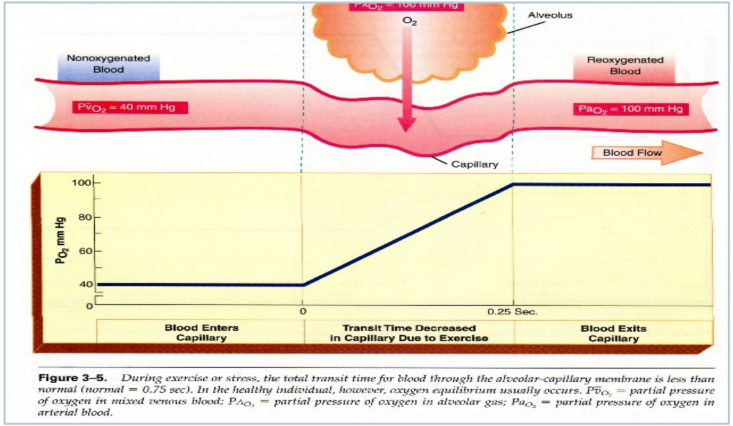


Figure 3–5. *During exercise or stress, the total transit time for blood through the alveolar-capillary membrane is less than normal (normal = 0.75 sec). In the healthy individual, however, oxygen equilibrium usually occurs. $P\bar{v}_{O_2}$ = partial pressure of oxygen in mixed venous blood; $P_{A_{O_2}}$ = partial pressure of oxygen in alveolar gas; Pa_{O_2} = partial pressure of oxygen in arterial blood.*

Diffusing capacity for carbon dioxide

01 It **diffuses 20 times greater than oxygen** due to greater diffusion coefficient which is 20 times that for oxygen.

02 Diffusion capacity for carbon dioxide **during rest** = 400ml/min/mmH.

03 During exercise 1200 to 1300 ml/min/mm.

04 CO2 is the most diffusing gas across the respiratory membrane.(Because of Solubility)

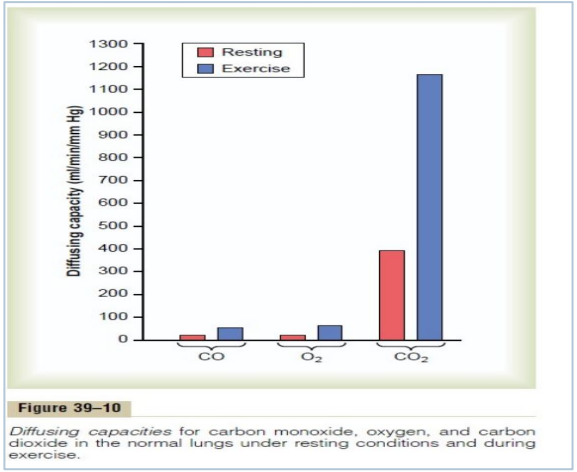
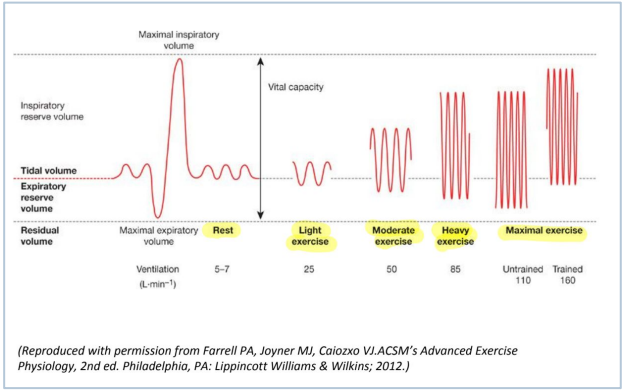


Figure 39–10

Diffusing capacities for carbon monoxide, oxygen, and carbon dioxide in the normal lungs under resting conditions and during exercise.



(Reproduced with permission from Farrell PA, Joyner MJ, Caiozzo VJ.ACSM's Advanced Exercise Physiology, 2nd ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2012.)

Breathing pattern during exercise

Recovery of the Aerobic System after Exercise

Oxygen debt

It is the **amount of extra O2** that must be taken after strenuous exercise to restore the muscles to the resting conditions.

When a person stops exercising, the rate of oxygen uptake **does not immediately return to pre-exercise levels**; It returns slowly (the person continues to breathe heavily for at least a few minutes and sometimes for as long as 1 hour thereafter).

This extra oxygen is used to repay the oxygen debt acquired during exercise.

Helpful video from slides

How much is the Oxygen Debt after heavy exercise ?

The body contains about **2 liters** of stored oxygen which can be used for aerobic metabolism even without breathing any new oxygen.

Stored oxygen Consists of : (Total = 2L)

01 **0.5** liter in the air of the lungs.

02 **0.25** liter dissolved in the body fluids.

03 **0.3** liter stored in the muscle fibers, combined mainly with myoglobin, and hemoglobin.

04 **1** liter combined with the hemoglobin of the blood.

Stored O2 **During** heavy exercise	In heavy exercise, almost **all this stored oxygen is used** within a minute or so for aerobic metabolism.	❖ In addition (to the consumption of stored O2), about 9 liters more oxygen **must be consumed** to reconstitute the **phosphagen system** and the **lactic acid system**. ❖ All this extra oxygen that must be "repaid," about 11.5 liters, is called the oxygen debt. (2+9≈11.5)
Stored O2 **After** the exercise	After the exercise is over, this stored oxygen **must be replenished** by breathing extra amounts of oxygen over and above the normal requirement.	

The principles of O2-debt

The rate of oxygen uptake from the figure	
During exercise	After exercise
During the first 4 minutes, the person exercises heavily, and the rate of oxygen uptake increases more than 15-fold.	Even after the exercise, the oxygen uptake still remains above normal. There's a gradual decrease (not sudden) but still higher than normal, because O2 is needed to restore the resting condition.

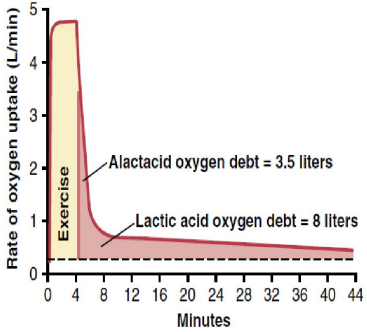


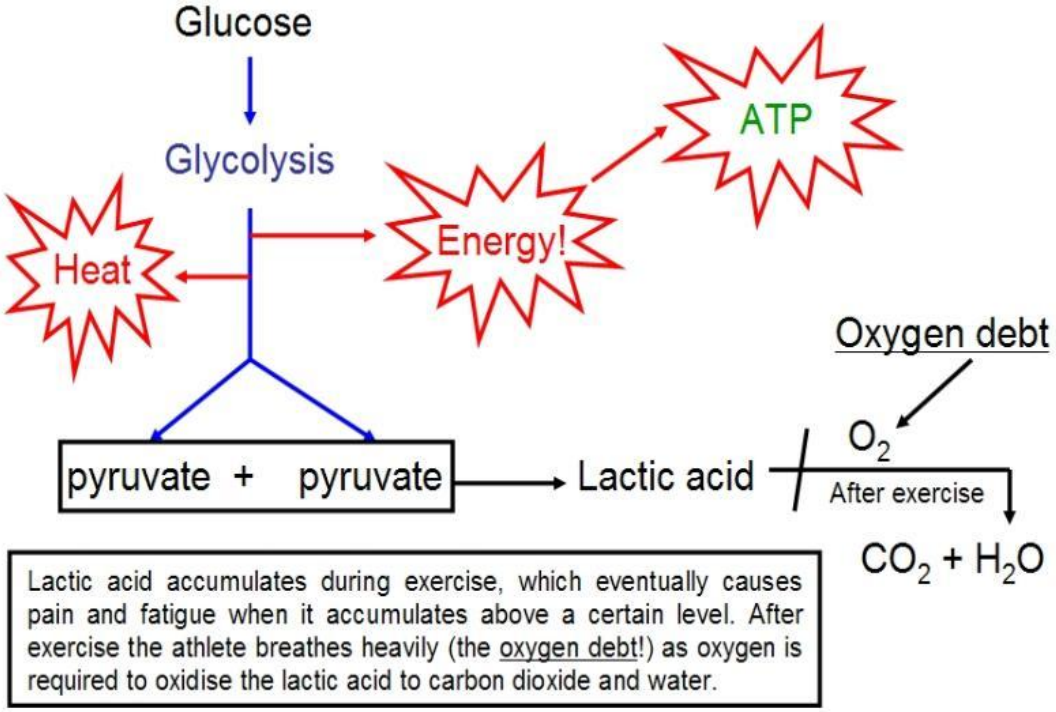
Figure 85-3 Rate of oxygen uptake by the lungs during maximal exercise for 4 minutes and then for about 40 minutes after the exercise is over. This figure demonstrates the principle of *oxygen debt*.

O2 uptake after the exercise	
At first	Later
At first it is very high while the body is reconstituting the phosphagen system and repaying the stored oxygen portion of the oxygen debt [**Alactic** acid O2 debt]= 3.5 L. (443: Alactic acid : Not lactic acid)	Then it is still above normal at a lower level for another 40 minutes while the lactic acid is removed [Lactic acid O2 debt] = 8 L.

Uses of the Oxygen Debt After Completion of Strenuous Exercise

Oxygen Debt is about 11.5 L of O2, this additional oxygen is used to:

- **Reconvert the lactic acid** that has accumulated during exercise back **into glucose.**
- **Re-establish** normal concentrations of oxygen bound with **hemoglobin and myoglobin.**
- Reconvert adenosine monophosphate and **ADP to ATP.**
- **Raise** the concentration of **oxygen** in the **lungs** to its **normal** level.
- Reconvert creatine and **phosphate to phosphocreatine.**


Glucose
Glycolysis
ATP
Energy!
Heat
Oxygen debt
O_2
pyruvate + pyruvate
Lactic acid
After exercise
$CO_2 + H_2O$
Lactic acid accumulates during exercise, which eventually causes pain and fatigue when it accumulates above a certain level. After exercise the athlete breathes heavily (the oxygen debt!) as oxygen is required to oxidise the lactic acid to carbon dioxide and water.

O2 debt

Effects of Smoking on Pulmonary Ventilation in Exercise

01 Nicotine

- Constricts the terminal bronchioles and **increases resistance of airflow** into and out of the lungs.
(Nicotine promotes barrier formation on the respiratory membrane which makes it difficult for O2 to enter).
- Nicotine **paralyze the cilia** of the respiratory epithelial cell surface. This lead to fluid and waste accumulation and **reduced level of performance**.

02 Smoke irritation

Causes **increased fluid secretion** into the bronchial tree and swelling of epithelial layer.

03 Chronic smoking

Smokers **may develop emphysema** (Obstruction of bronchioles + chronic bronchitis + destruction of alveoli) so slight exercise cause respiratory distress.

What Cause hyperventilation During Exercise ?

01

Neural signals from the motor areas of the brain to the respiratory center.

The **motor cortex** of the brain, on transmitting motor impulses to the exercising muscles,transmits at the same time collateral impulses into the brain stem to excite the respiratory center.

02

An additional sensory signals transmitted into the respiratory center from the contracting muscles and moving joints (proprioceptors).

03

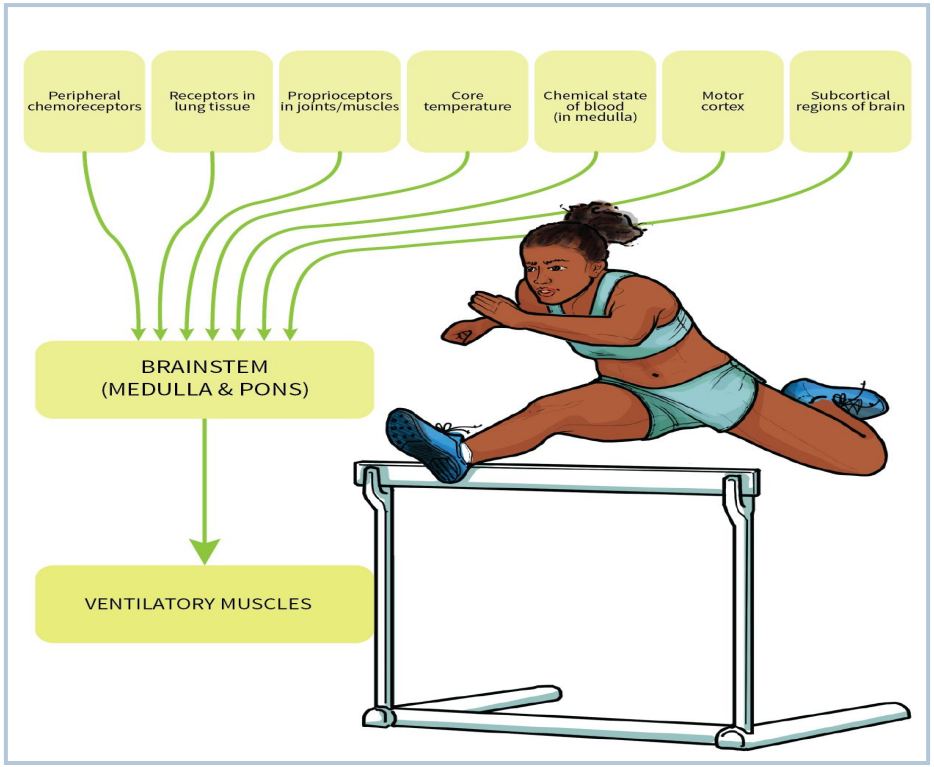
Increased body temperature → stimulates the (hypothalamus) → stimulates the respiratory centers.

04

Possibility that the neurogenic factor (the impulses from the motor cortex) for control of ventilation during exercise is a learned response (conditioned reflex).

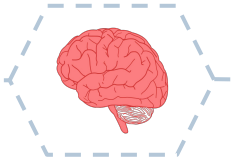
Regulation of exercise hyperpnea

🩺 Doctor said:
This is Summary of all things we discussed



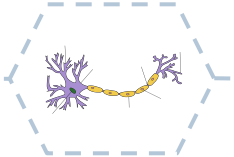
Relation between Chemical and Nervous factors in the control of respiration during exercise

Brain



Direct nervous signal stimulate the respiratory center almost the proper amount to supply the extra oxygen required for exercise and to blow off extra carbon dioxide

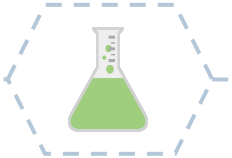
Nervous respiratory system



Occasionally, the nervous respiratory control signals are either :

- **too weak**
- **too strong**

Chemical factors



Then chemical factors play a significant role in bringing about the final adjustment of respiration required to keep the O_2, CO_2, and H^+ ion concentrations of the body fluids as **nearly normal as possible**

Med442:
Chemical factors only play a major role when the impulses are too strong or too weak (which happen sometimes), but most of the time impulses are normal and the factors that play a major role are the nervous factors.

Dr:Stay healthy & exercise!!!

MCQs

Thanks to Team 443 :3

Q1: Alactic acid debt is equal to ?			
A- 3.5	B- 8	C- 9	D- 11.5
Q2: Whats the normal oxygen consumption at rest ?			
A- 21 ml/min/mmHg	B- 250 ml/min	C- 64 ml/mmHg/min	D- 11 mmHg
Q3: During strenuous exercise, O2 consumption and CO2 formation can increase as much as 20-fold. Va increases almost exactly in step with the increase in O2 consumption. Which option best describes what happens to the mean arterial O2 tension (Po2), CO2 tension (Pco2),and pH in a healthy athlete during strenuous exercise? (Arterial PO2/Arterial PCO2/Arterial PH)			
A-PH Increase	B-No change	C-All decreased	D-PO2 Increase

1-A 2-B 3-B

MCQs

Q4: Excess post exercise O2 consumption (Oxygen Debt) used for what of following ?			
A- decrease concentration of O2	B- Reconvert lactic acid	C- ATP TO ADP	D- None
Q5: which of the following play a significant role in bringing about the final adjustment of respiration required to keep the O2, CO2, and H+ ion concentrations of the body fluids as nearly normal ?			
A- Chemical factors	B- Nervous factors	C- Epinephrine	D- Joint
Q6: Which part of the brain responds to changes in our body temperature and stimulates an increase in ventilation ?			
A- Teeth	B- Hypothalamus	C- Cerebellum	D- Cerebral Cortex

4-B 5-A 6-B

SAQs

Q1: Why does the diffusing capacity for oxygen increases about three times during exercise ?

Q2: Enumerate Three uses of the additional oxygen consumption After Completion of Strenuous Exercise ?

Q3: Enumerate the sources of impulses during exercise ?

A1: Slide 8

A2: Slide 14

A3: Slide 17 >
1- Motor cortex.
2- Increased Temperature.
3- Proprioceptors in joints /muscles.

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Abdulmohsen Alrahaimi

Abdulaziz Nasser

Abdullah Almarwan

Saud Alsaeed

Abdullah Almutlaq

Talal Alrobaian

Khalid Al Tameem

Zyad Alshuhail

Abdulaziz Alobathani 👑

Moath Alabdulsalam

Omar Alattas

Khalid Alkanhal

Marwah Fal

Ghala Alyousef

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Aljoharah Alyahya

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