CHAPTER 9

CARDIOVASCULAR AND RESPIRATORY ADAPTATIONS TO TRAINING

Learning Objectives

- Learn how cardiorespiratory endurance differs from muscular endurance.
- Review how cardiorespiratory endurance is measured.
- Find out what changes occur in the oxygen transport system as a result of endurance training.
- Examine metabolic adaptations that occur due to endurance training.

(continued)

Learning Objectives

- Discover how adaptations to cardiovascular, respiratory, and metabolic function affect an athlete's endurance capacity.
- Learn why cardiorespiratory adaptations benefit performance in both endurance and nonendurance sports.

Endurance Training

Muscular Endurance

- Ability of a single muscle or muscle group to sustain high-intensity, repetitive, or static exercise that occurs in repeated 1- to 2-minute bursts
- Related to muscular strength and anaerobic development

Cardiorespiratory Endurance

- Ability of the whole body to sustain prolonged, steady-state exercise
- Related to cardiovascular and respiratory system (aerobic) development

Evaluating Endurance Capacity

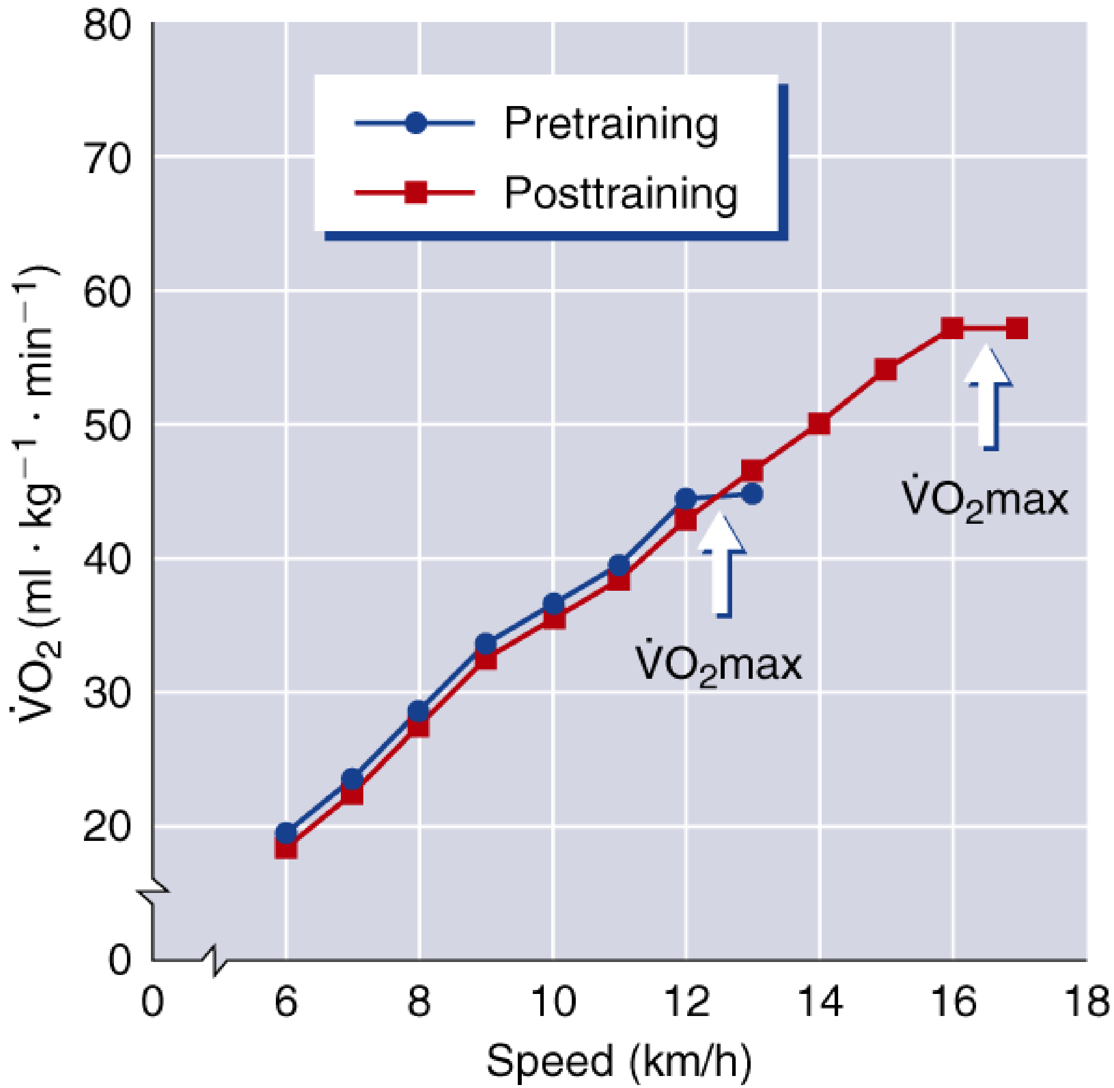
$\dot{V}O_2max$

- Highest rate of oxygen consumption attainable during maximal exercise
- Can be increased with endurance training

Submaximal Endurance Capacity

- Closely related to competitive endurance performance; determined by $\dot{V}O_2max$ and lactate threshold
- More difficult to evaluate since there is no one physiological variable that can be measured to quantify it
- Can also be increased with endurance training

CHANGES IN $\dot{V}O_2$MAX WITH TRAINING



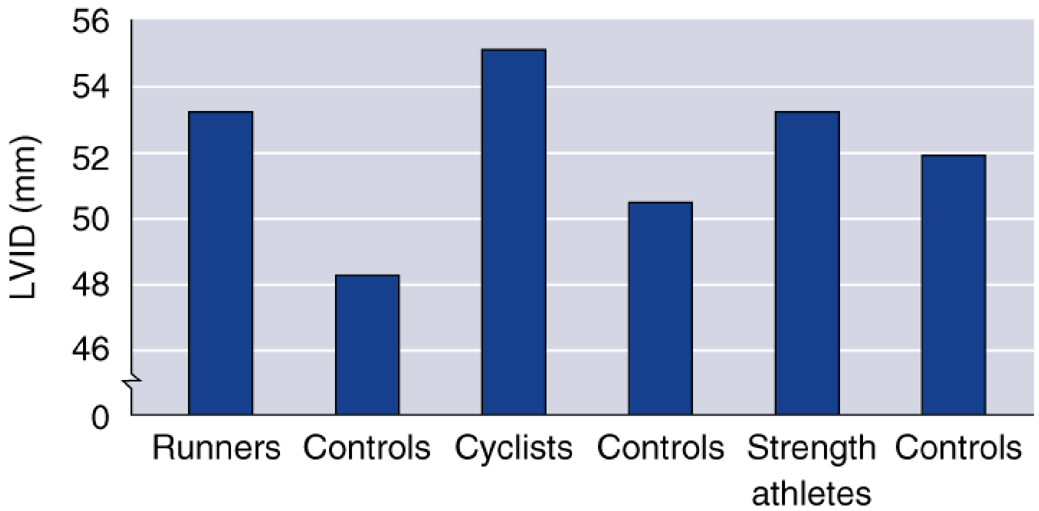
Parameters Affected by Training

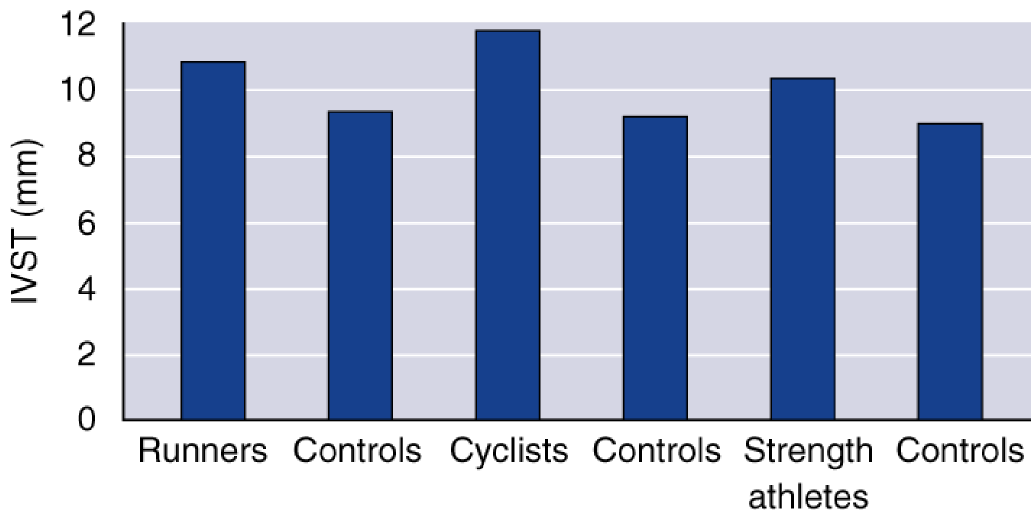
- Heart size
- Stroke volume
- Heart rate
- Cardiac output
- Blood flow
- Blood pressure
- Blood volume

Oxygen Transport System

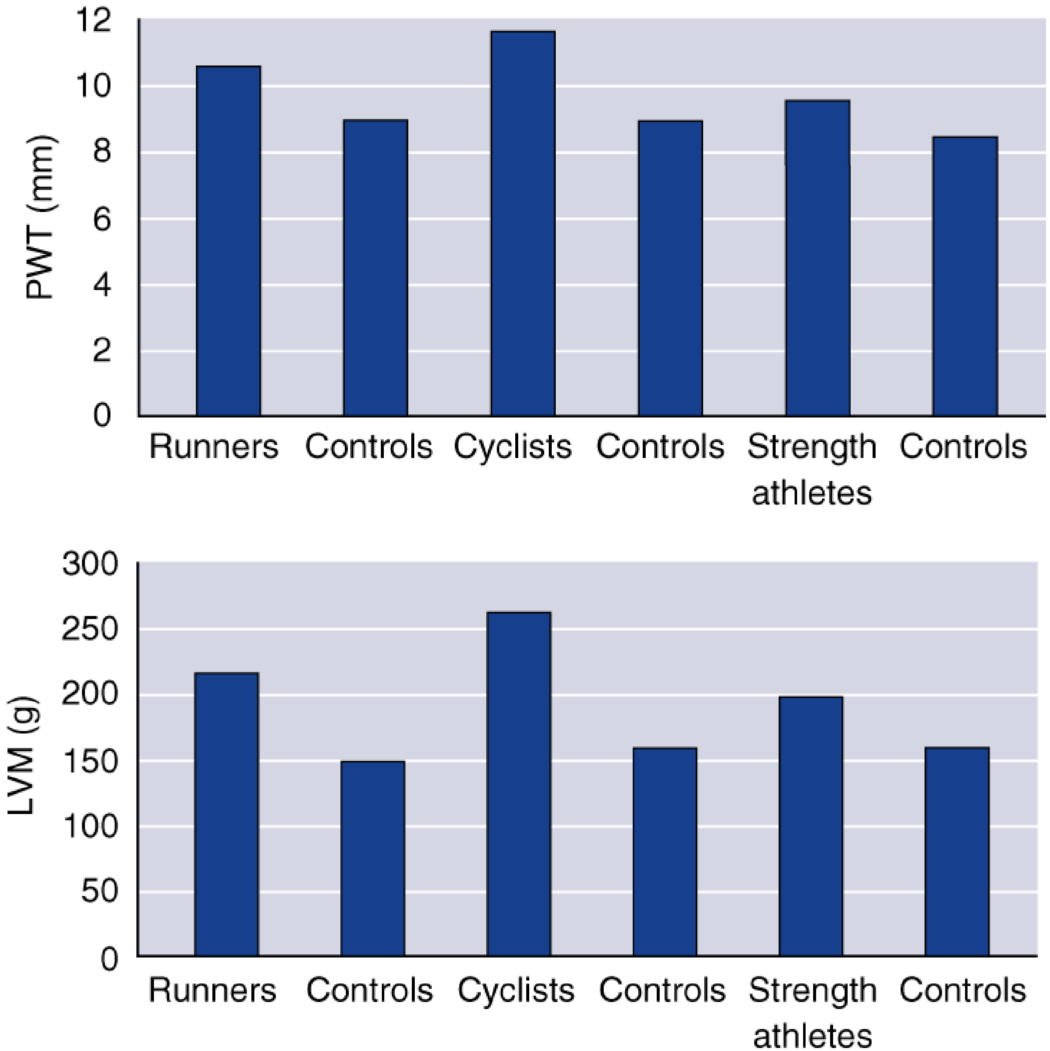
- Components of the cardiorespiratory system that transport O_2 to and from active tissues
- Evaluated with the Fick equation:
  $\dot{V}O_2 = SV \times HR \times a\text{-}\bar{v}O_2$ diff
- Can transport O_2 more efficiently with adaptations that occur with endurance training

DIFFERENCES IN HEART SIZE

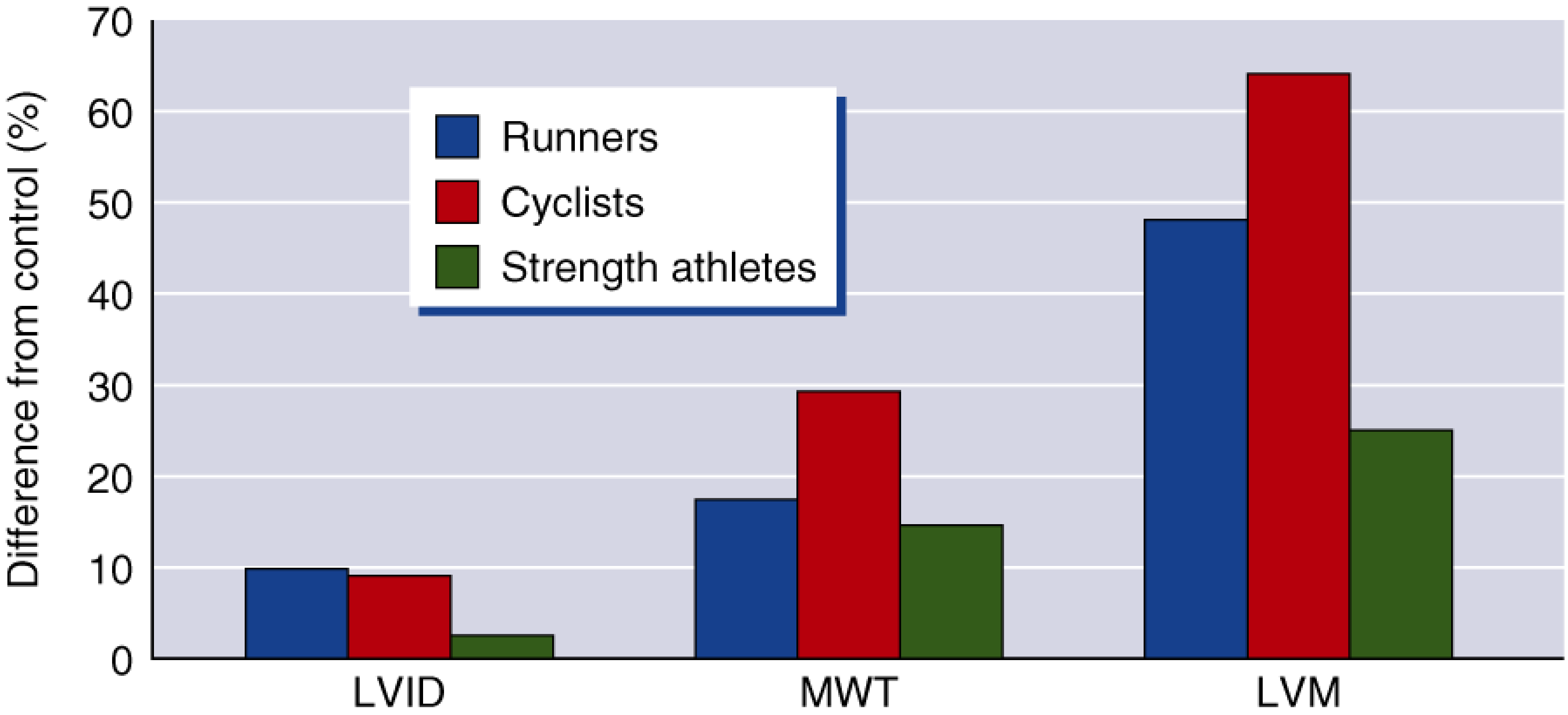




DIFFERENCES IN HEART SIZE



DIFFERENCES IN HEART SIZE

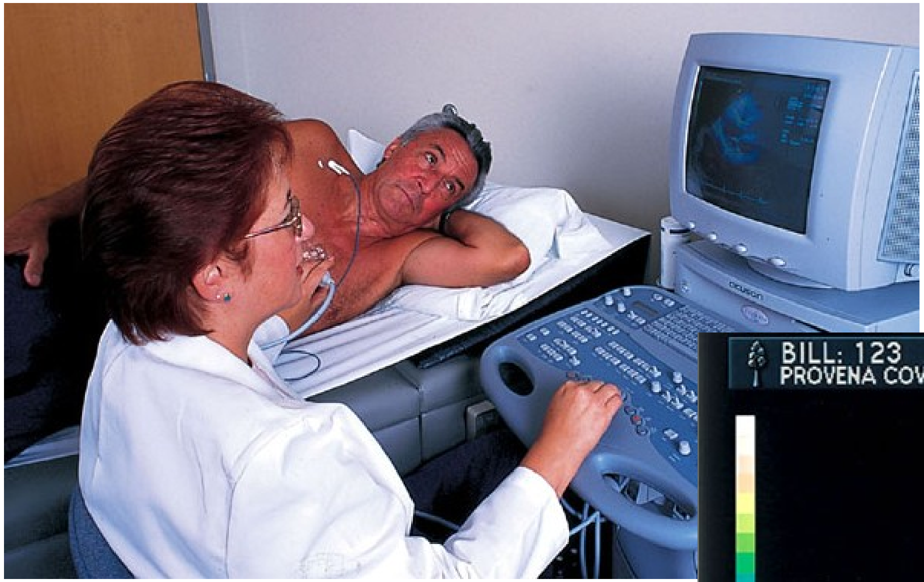


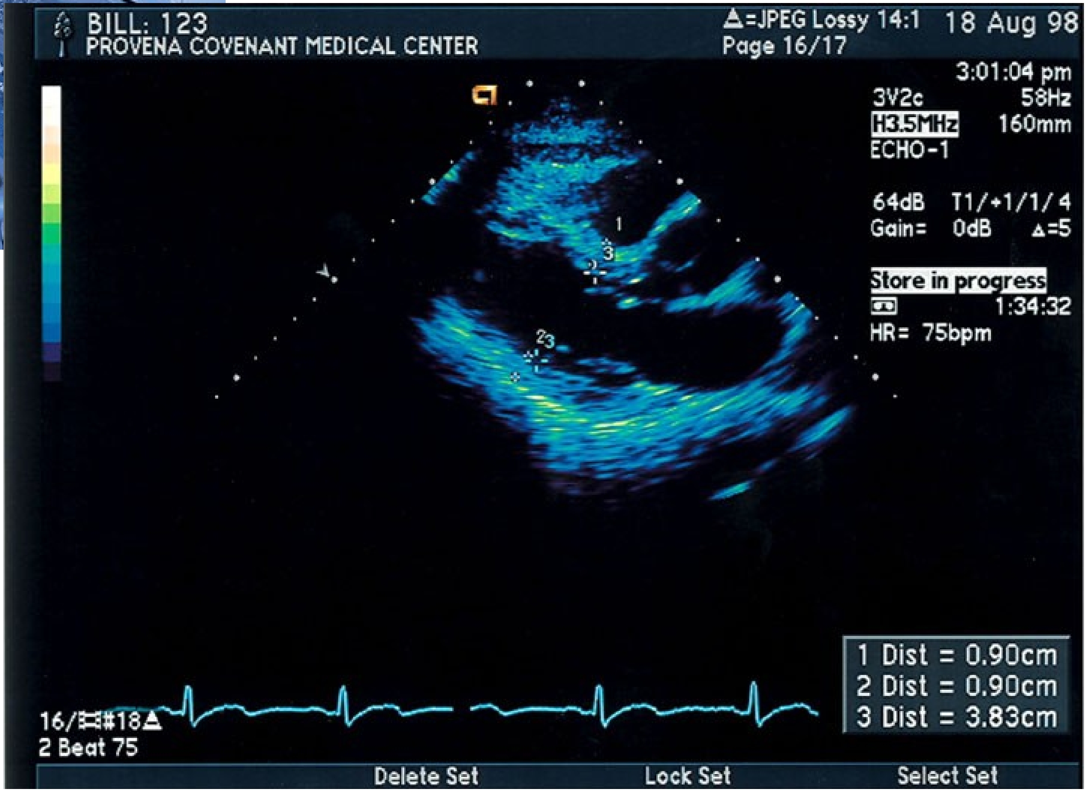
Key Points

Heart Size Adaptations

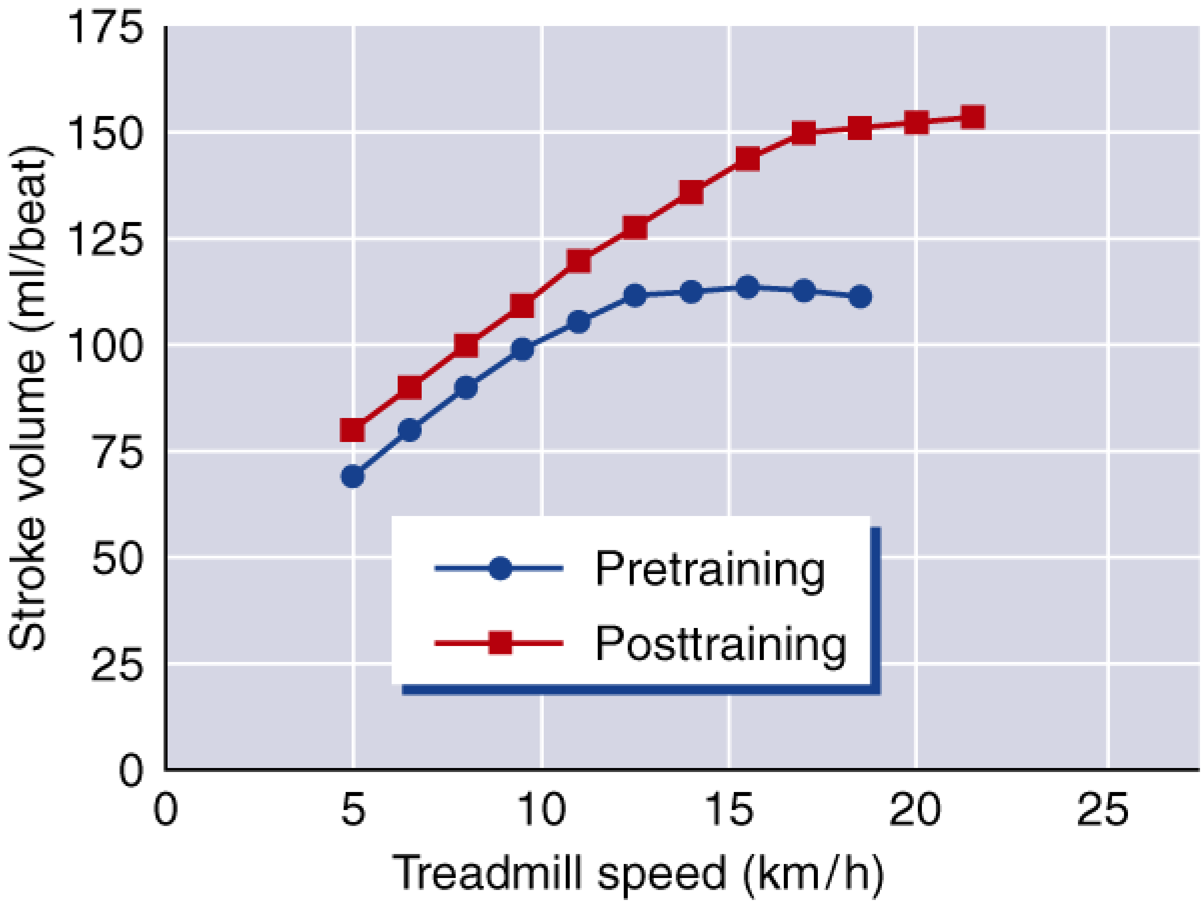
- The left ventricle changes the most in response to endurance training.
- The internal dimensions of the left ventricle increase mostly due to an increase in ventricular filling.
- The wall thickness of the left ventricle increases, allowing a more forceful contraction of the left ventricle.

MEASURING HEART SIZE





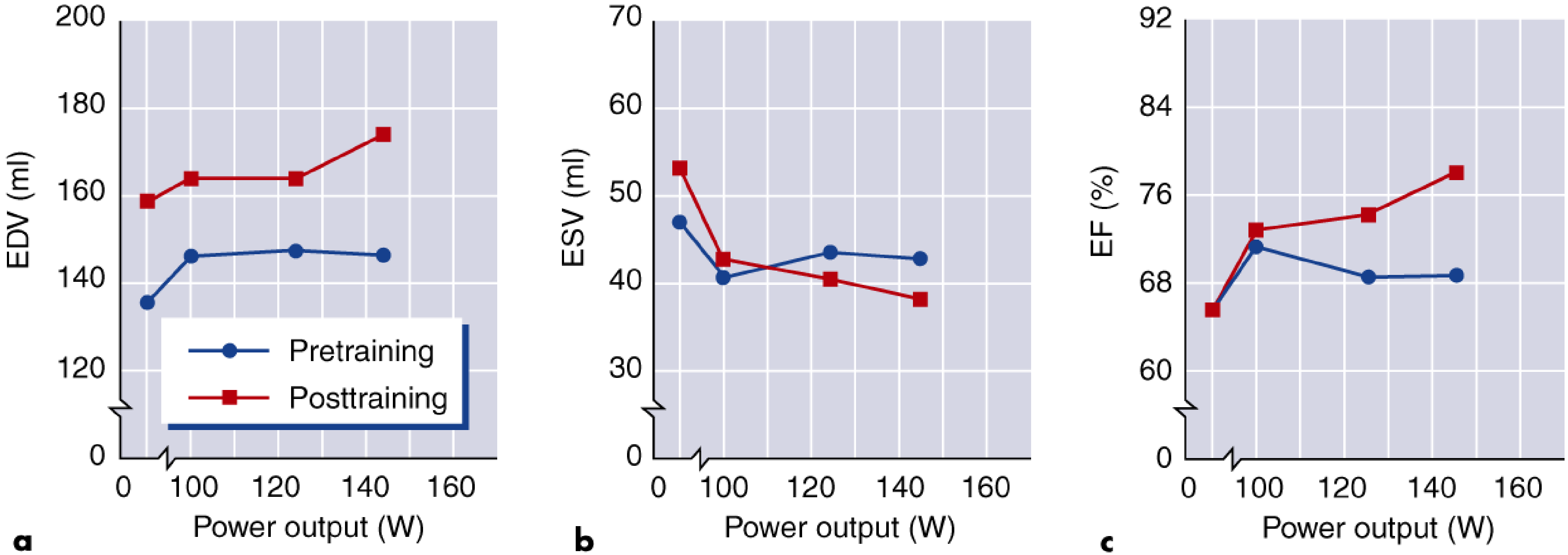
STROKE VOLUME AND TRAINING



Stroke Volumes (SV) for Different States of Training

Subjects	SVrest (ml)	SVmax (ml)
Untrained	50-70	80-110
Trained	70-90	110-150
Highly trained	90-110	150-220

DIFFERENCES IN EDV, ESV, AND EF

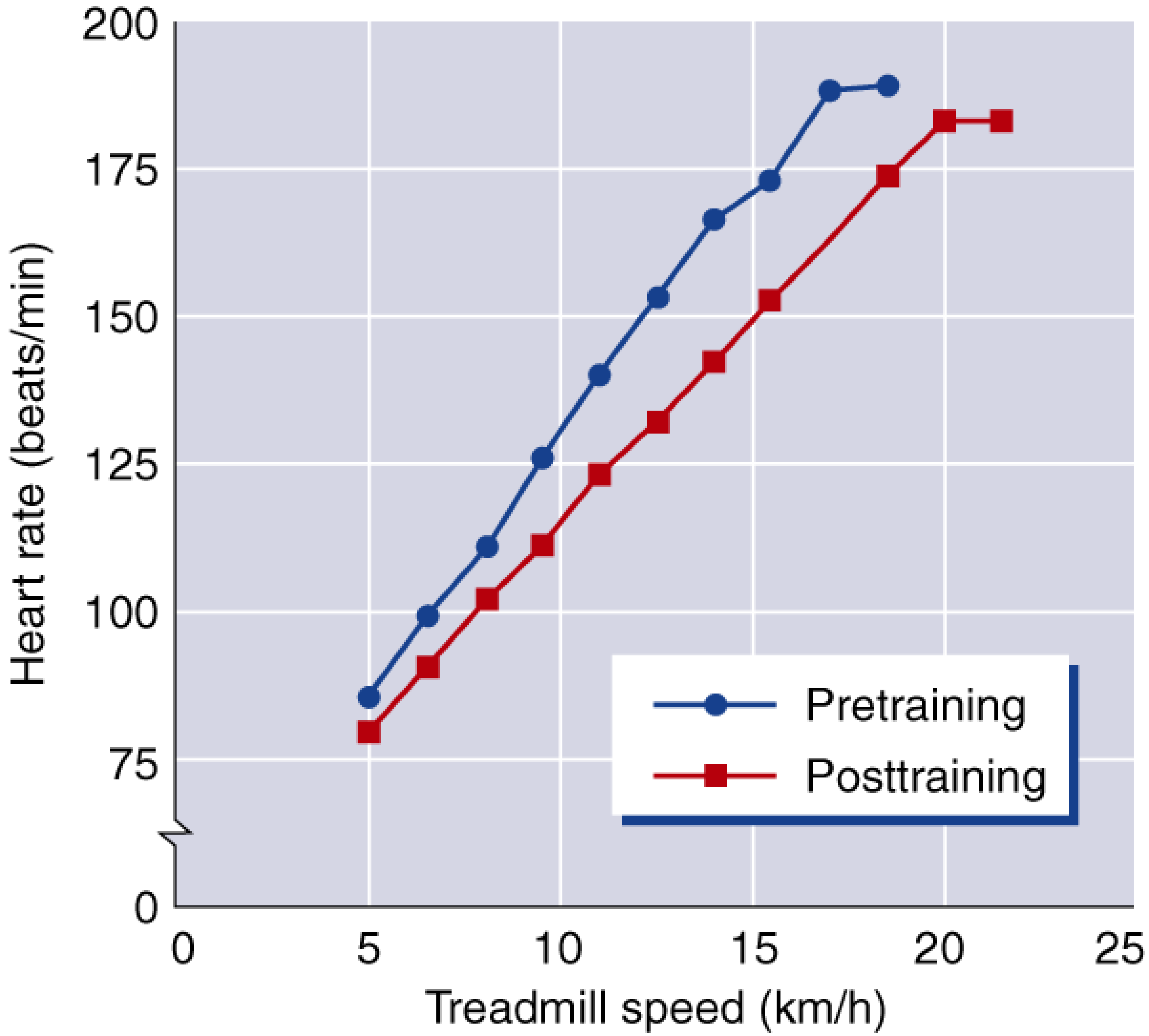


Key Points

Stroke Volume Adaptations

- Endurance training increases SV at rest and during submaximal and maximal exercise.
- End diastolic volume increases, caused by an increase in blood plasma and greater diastolic filling time, contributing to increased SV.
- The increased size of the heart allows the left ventricle to stretch more and fill with more blood; wall thickness increases enhance contractility. Reduced systemic blood pressure lowers the resistance to the flow of blood pumped from the left ventricle.

HEART RATE AND TRAINING



Resting Heart Rate

- Decreases with endurance training likely due to more blood returning to heart and changes in autonomic control
- Sedentary individuals can decrease RHR by 1 beat/min per week during initial training, but several recent studies have shown small changes of less than 3 beats/min with up to 20 wk of training
- Highly trained endurance athletes may have resting heart rates of 30 to 40 beats/min

Heart Rate During Exercise

Submaximal

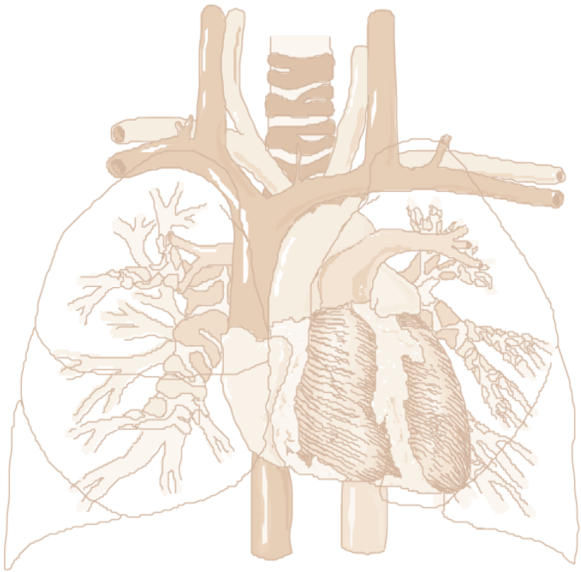
- Decreases proportionately with the amount of training completed
- May decrease by 10 to 30 beats/min after 6 months of moderate training at any given rate of work, with the decrease being greater at higher rates of work

Maximal

- Remains unchanged or decreases slightly
- A decrease might allow for optimal stroke volume to maximize cardiac output

Which Comes First?

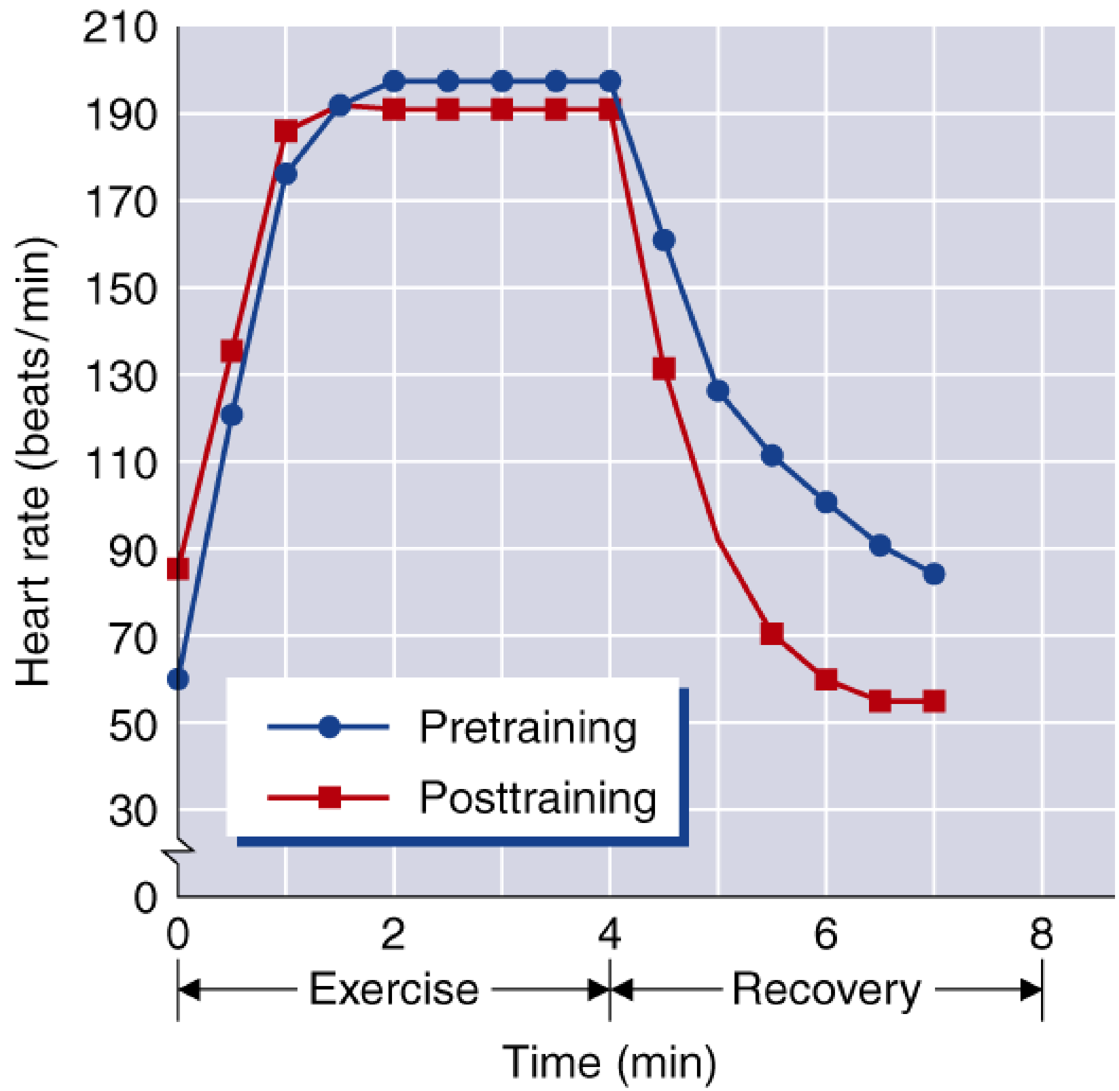
Does increased stroke volume allow a decreased heart rate or does decreased heart rate allow an increased stroke volume?



Heart Rate Recovery Period

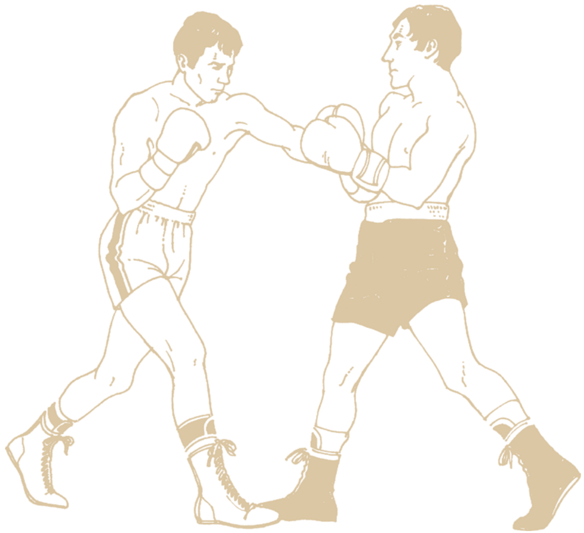
- The time after exercise that it takes your heart to return to its resting rate
- With training, heart rate returns to resting level more quickly after exercise
- Has been used as an index of cardiorespiratory fitness
- Conditions such as altitude or heat can affect it
- Should not be used to compare individuals to one another

HEART RATE RECOVERY AND TRAINING



Did You Know…?

Resistance training can lead to decreases in heart rate; however, these decreases are not as reliable or as large as those that occur due to endurance training.

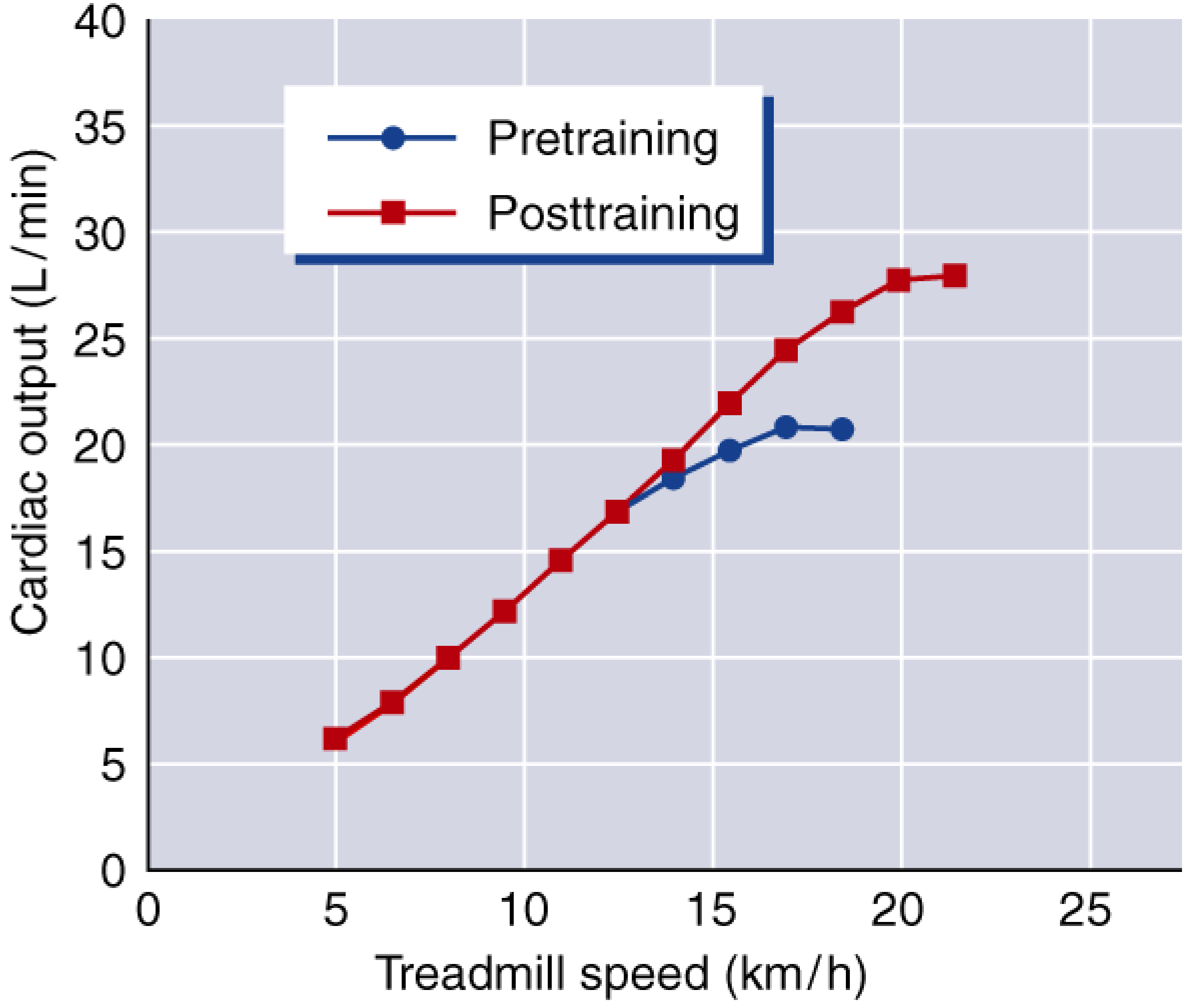


Key Points

Cardiac Output Adaptations

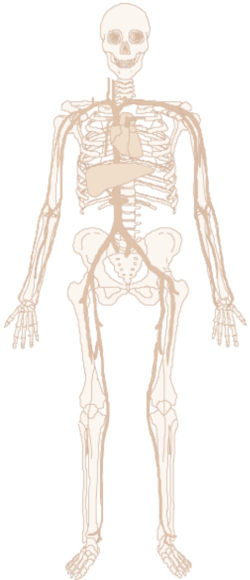
- $\dot{Q}$ decreases slightly or does not change at rest or during submaximal exercise.
- A slight decrease could be the result of an increase in the a-$\bar{v}O_2$ diff due to greater oxygen extraction by the tissues or to a reduction in the requirement for oxygen.
- $\dot{Q}$ increases dramatically at maximal exertion due to the increase in maximal SV.
- Absolute values of $\dot{Q}max$ range from 14 to 20 L/min in untrained people, 25 to 35 L/min in trained individuals, and 40 L/min or more in large endurance athletes.

CARDIAC OUTPUT AND TRAINING



Blood Flow Increases With Training

- Increased capillarization of trained muscles (higher capillary-to-fiber ratio)
- Greater opening of existing capillaries in trained muscles
- More effective blood redistribution—blood goes where it is needed
- Increased blood volume

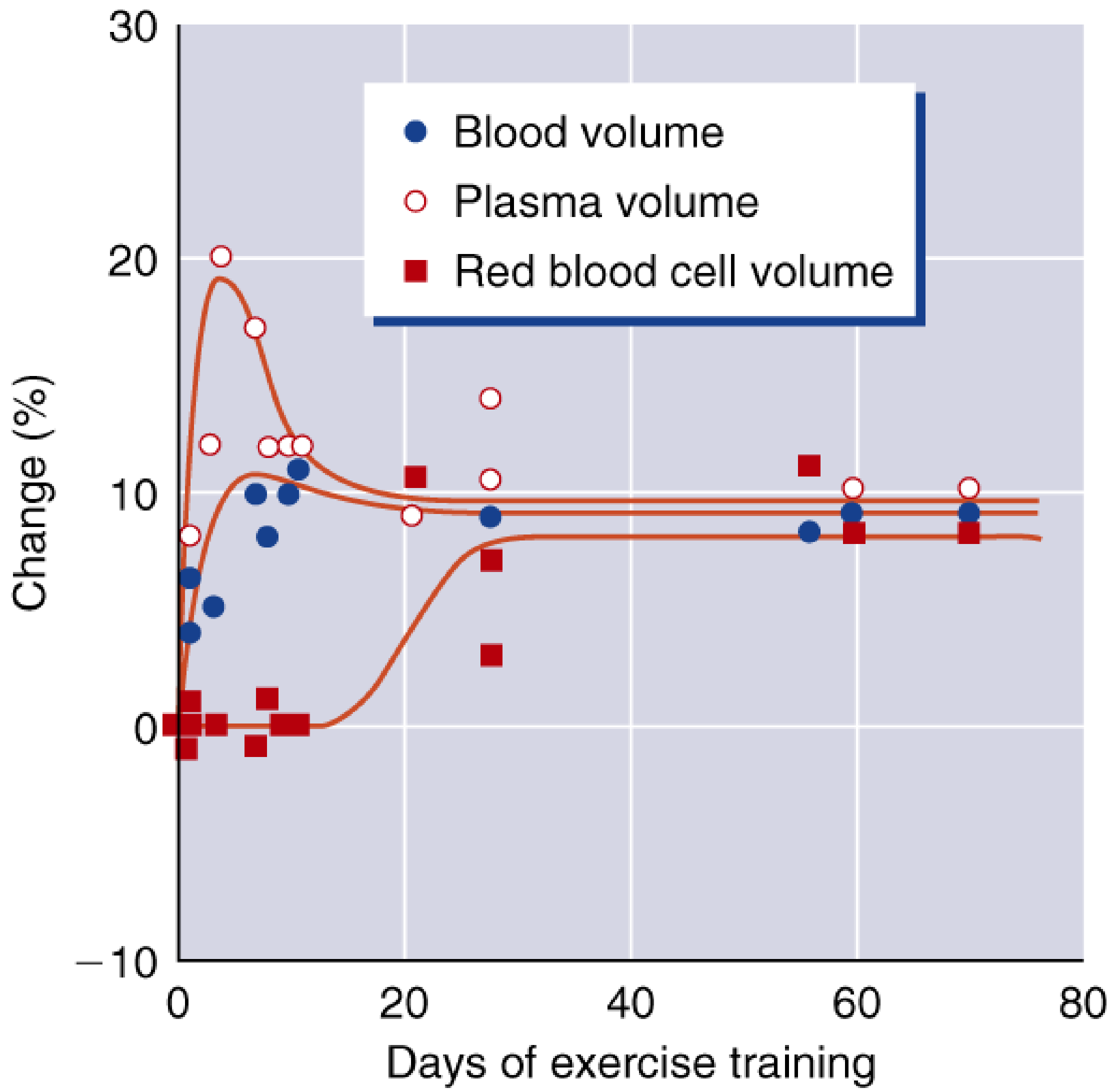


Key Points

Blood Pressure and Training

- Endurance training results in reduced blood pressure at the same submaximal work rate, but at maximal work rates systolic pressure increases and diastolic pressure decreases.
- Resting blood pressure (both systolic and diastolic) is lowered with endurance training in individuals with borderline or moderate hypertension.
- Blood pressure during lifting heavy weights can cause marked increases in systolic and diastolic blood pressure, but resting blood pressure after resistance training tends to not change and may decrease.

BLOOD VOLUME AND TRAINING

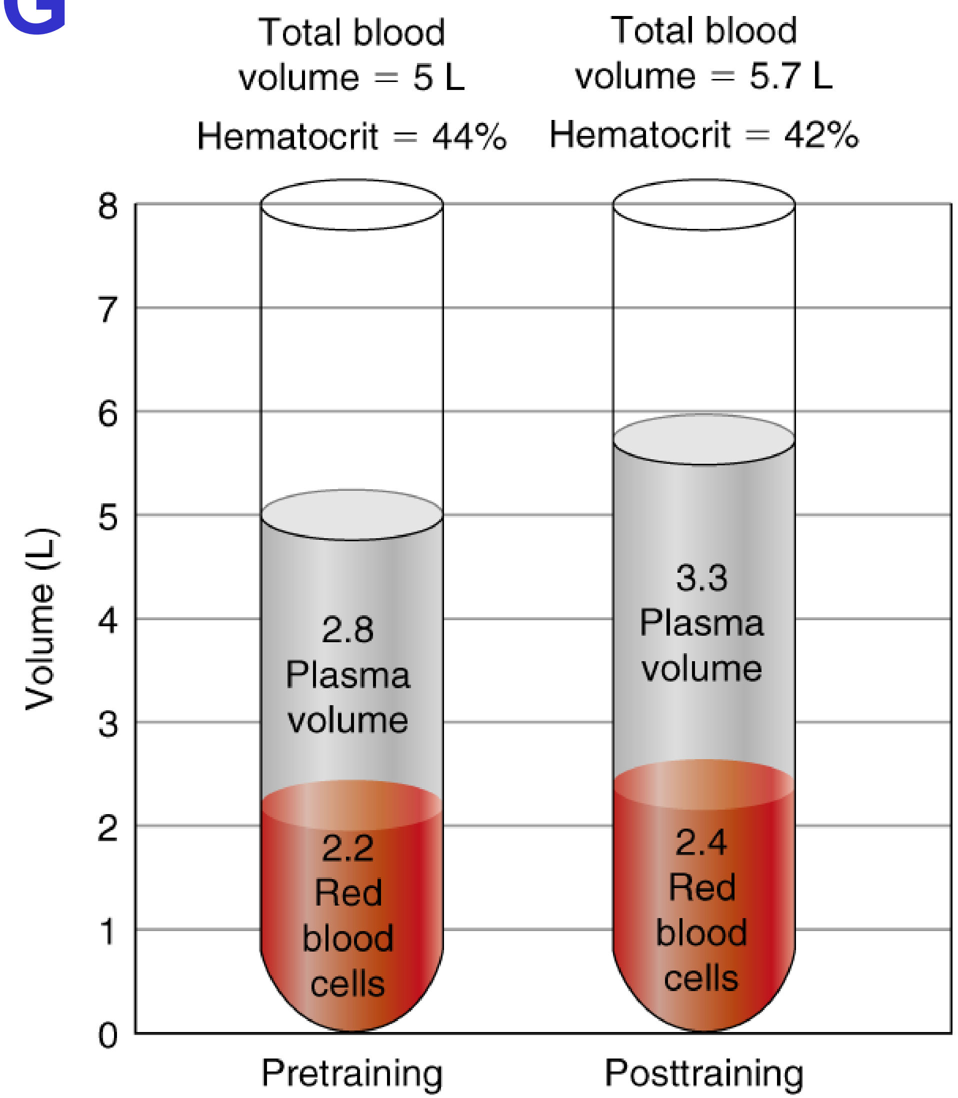


Key Points

Blood Volume and Training

- Endurance training, especially intense training, increases blood volume.
- Blood volume increases due primarily to an increase in plasma volume (increases in ADH, aldosterone, and plasma proteins cause more fluid to be retained in the blood).
- Red blood cell volume increases, but increase in plasma volume is higher; thus, hematocrit decreases.
- Blood viscosity decreases, thus improving circulation and enhancing oxygen delivery.
- Changes in plasma volume are highly correlated with changes in SV and $\dot{V}O_2max$.

BLOOD AND PLASMA VOLUME AND TRAINING



Cardiovascular Adaptations to Training

- Left ventricle size and wall thickness increase
- Resting, submaximal, and maximal stroke volume increases
- Maximal heart rate stays the same or decreases
- Cardiac output is better distributed to active muscles and maximal cardiac output increases
- Blood volume increases, as does red cell volume, but to a lesser extent
- Resting blood pressure does not change or decreases slightly, while blood pressure during submaximal exercise decreases

Key Points

Respiratory Adaptations to Training

- Pulmonary ventilation increases during maximal effort after training; you can improve performance by training the inspiratory muscles.
- Pulmonary diffusion increases at maximal work rates.
- The a-$\bar{v}O_2$ diff increases with training due to more oxygen being extracted by tissues.
- The respiratory system is seldom a limiter of endurance performance.
- All the major adaptations of the respiratory system to training are most apparent during maximal exercise.

Did You Know…?

Although the largest part of the increase in $\dot{V}O_2max$ results from the increases in cardiac output and muscle blood flow, the increase in a-$\bar{v}O_2$ diff also plays a key role. This increase in a-$\bar{v}O_2$ diff is due to a more effective distribution of arterial blood away from inactive tissue to the active tissue, so that more of the blood coming back to the right atrium has gone through active muscle.

Metabolic Adaptations to Training

Lactate threshold increases.

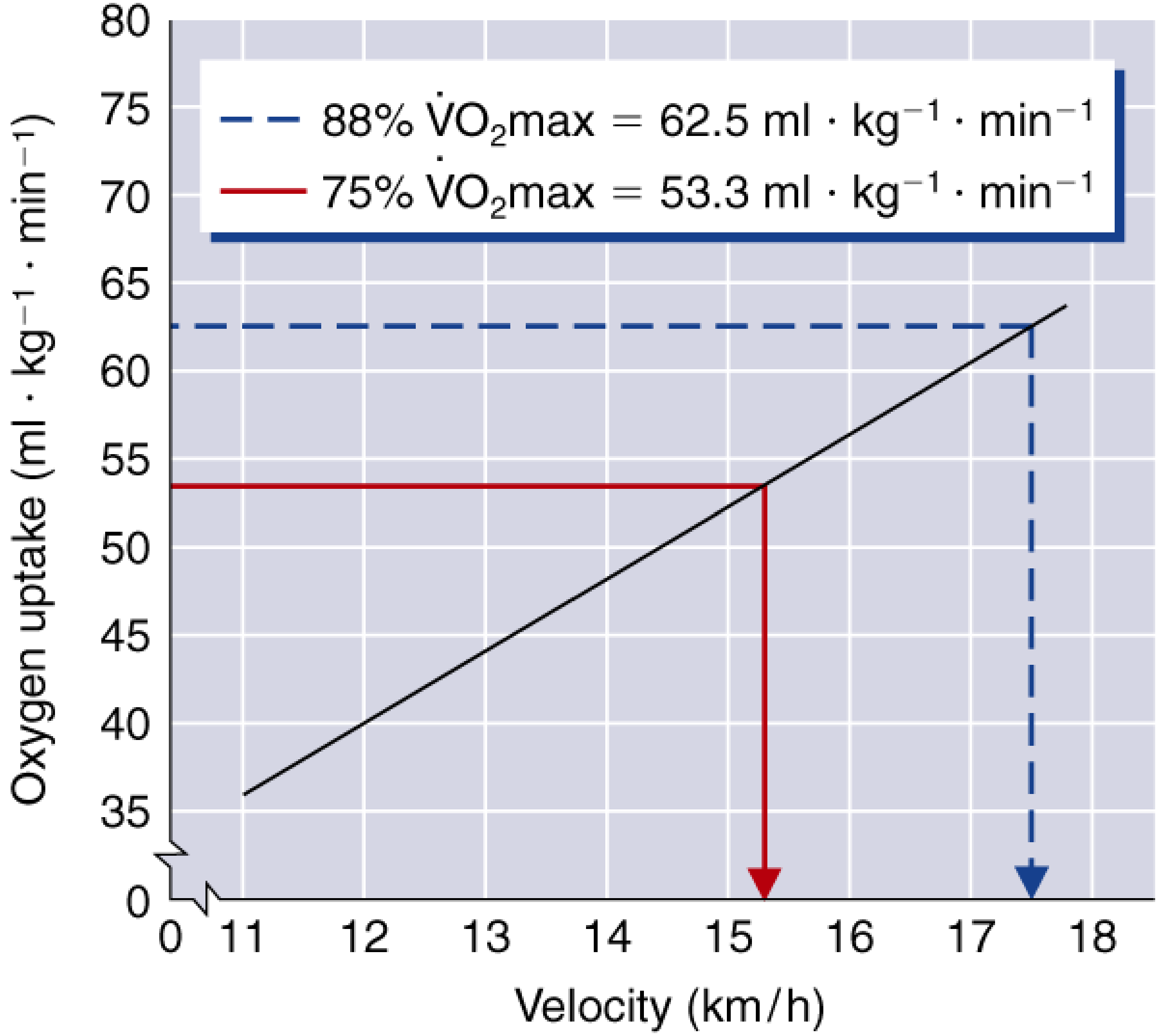
Respiratory exchange ratio

- decreases for submaximal efforts (greater use of FFAs), and
- increases at maximal levels.

Oxygen consumption ($\dot{V}O_2$) is

- unaltered or slightly increased at rest,
- unaltered or slighted decreased at submaximal rates of work, and
- increased at maximal exertion ($\dot{V}O_2$max—increases range from 0% to 93%).

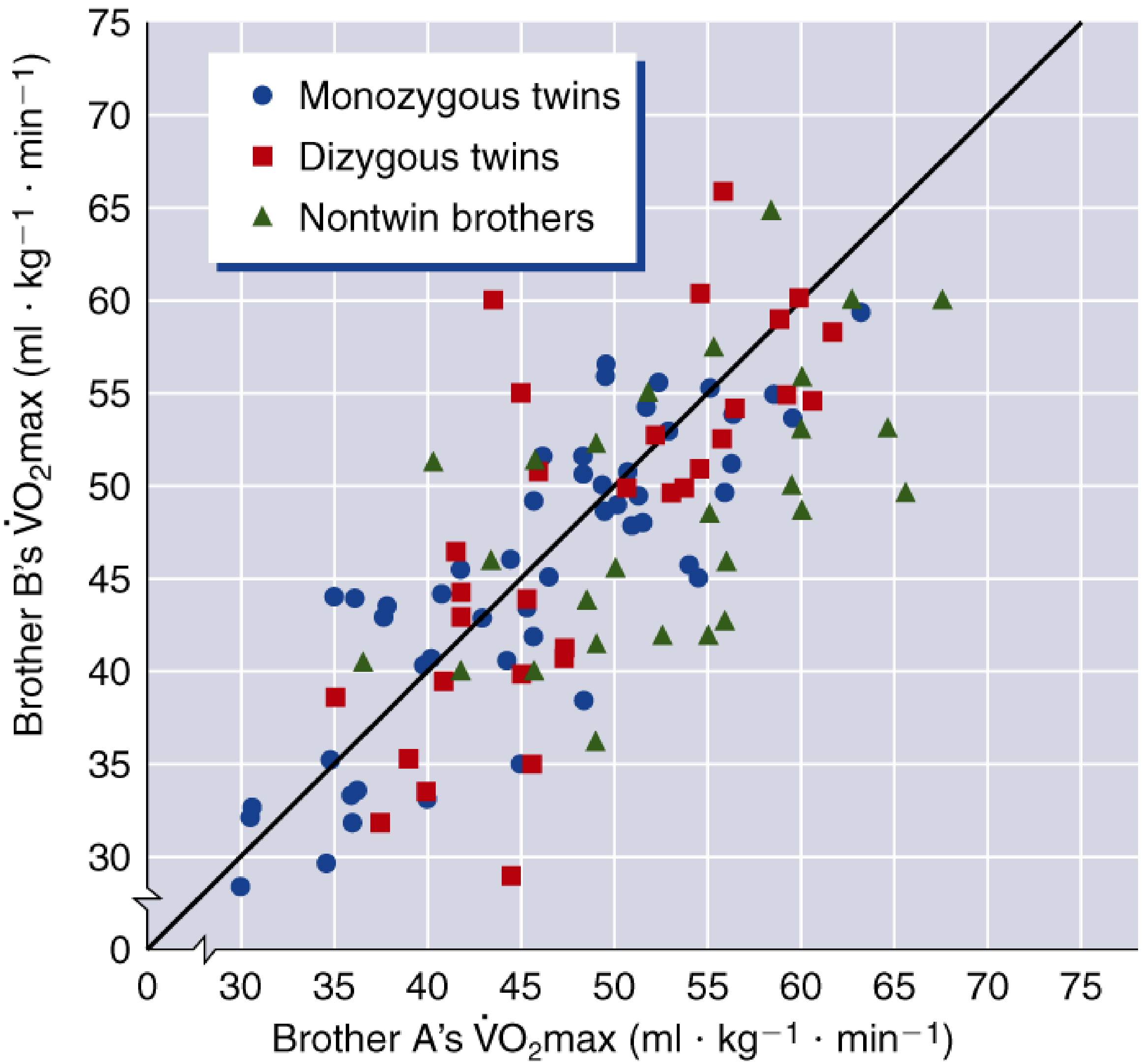
CHANGE IN RACE PACE, NOT $\dot{V}O_2MAX$



Did You Know…?

Once an athlete has achieved her genetically determined peak $\dot{V}O_2max$, she can still increase her endurance performance due to the body's ability to perform at increasingly higher percentages of that $\dot{V}O_2max$ for extended periods. The increase in performance without an increase in $\dot{V}O_2max$ is a result of an increase in lactate threshold.

$\dot{V}O_2$MAX COMPARISON IN BROTHERS



Factors Affecting $\dot{V}O_2max$

Level of conditioning—the greater the level of conditioning the lower the response to training

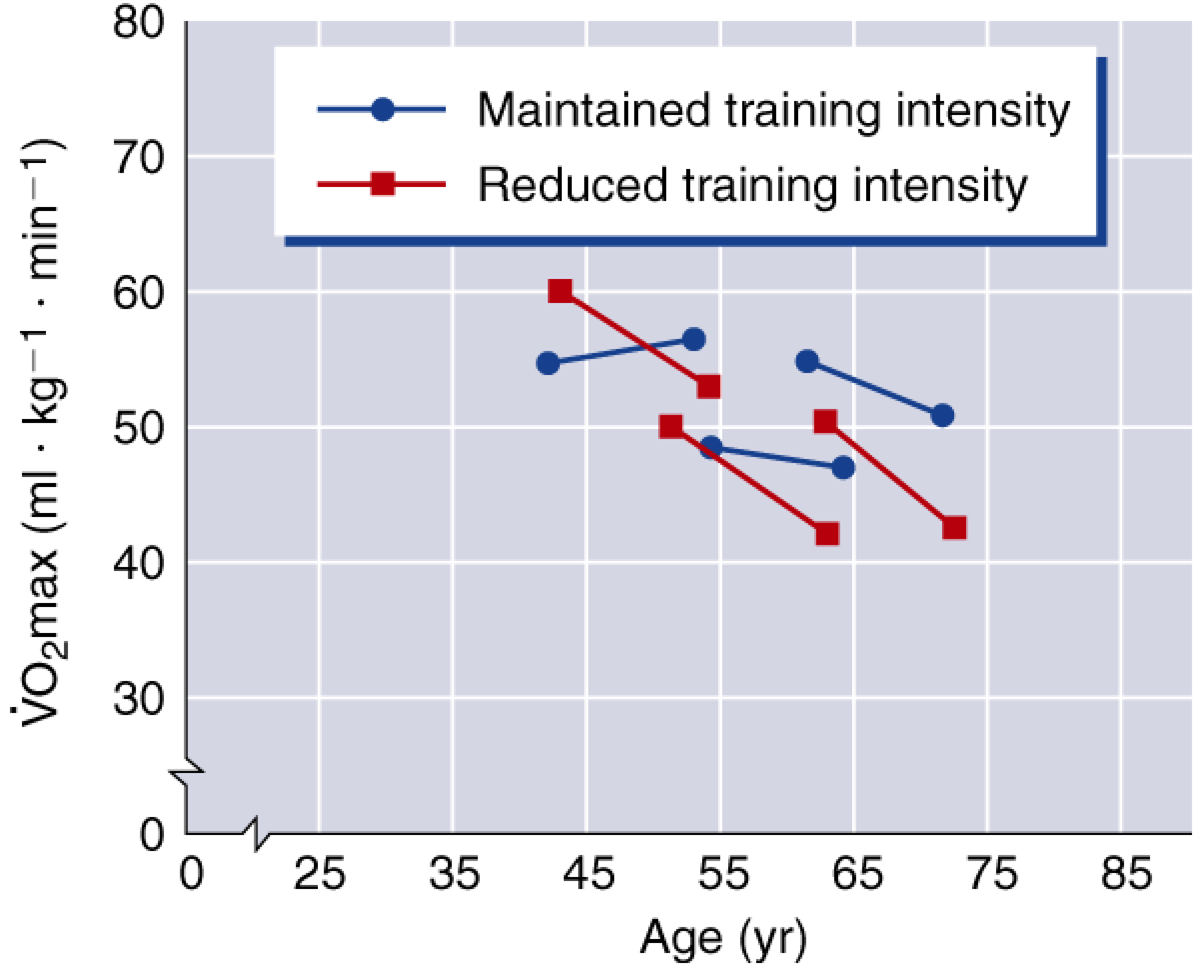
Heredity—accounts for slightly less than 50% of the variation as well as an individual's response to training

Age—decreases with age are associated with decreases in activity levels as well as decreases in physiological function

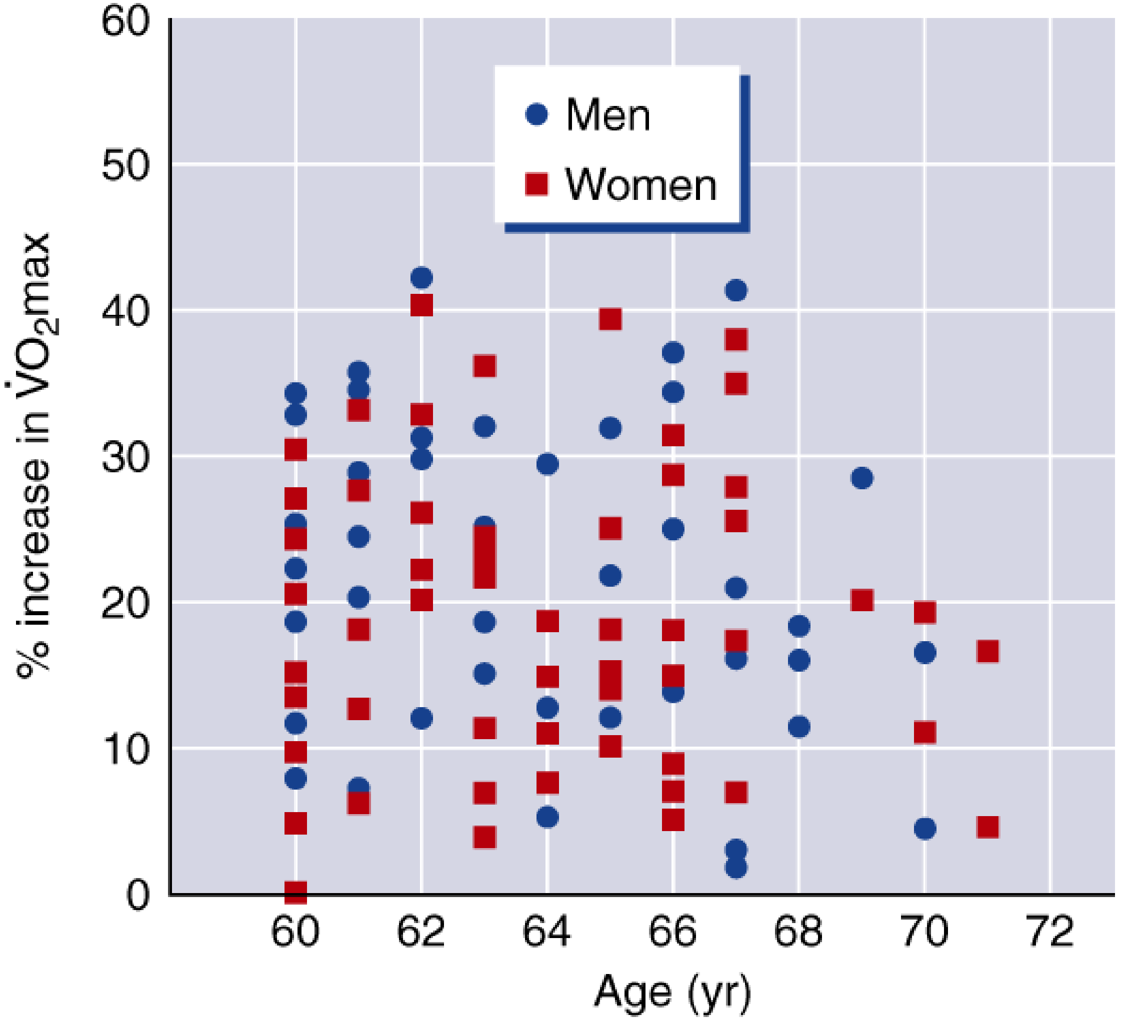
Sex—lower in women than men (20% to 25% lower in untrained women; 10% lower in highly trained women)

Specificity of training—the closer training is to the sport to be performed, the greater the improvement and performance in that sport

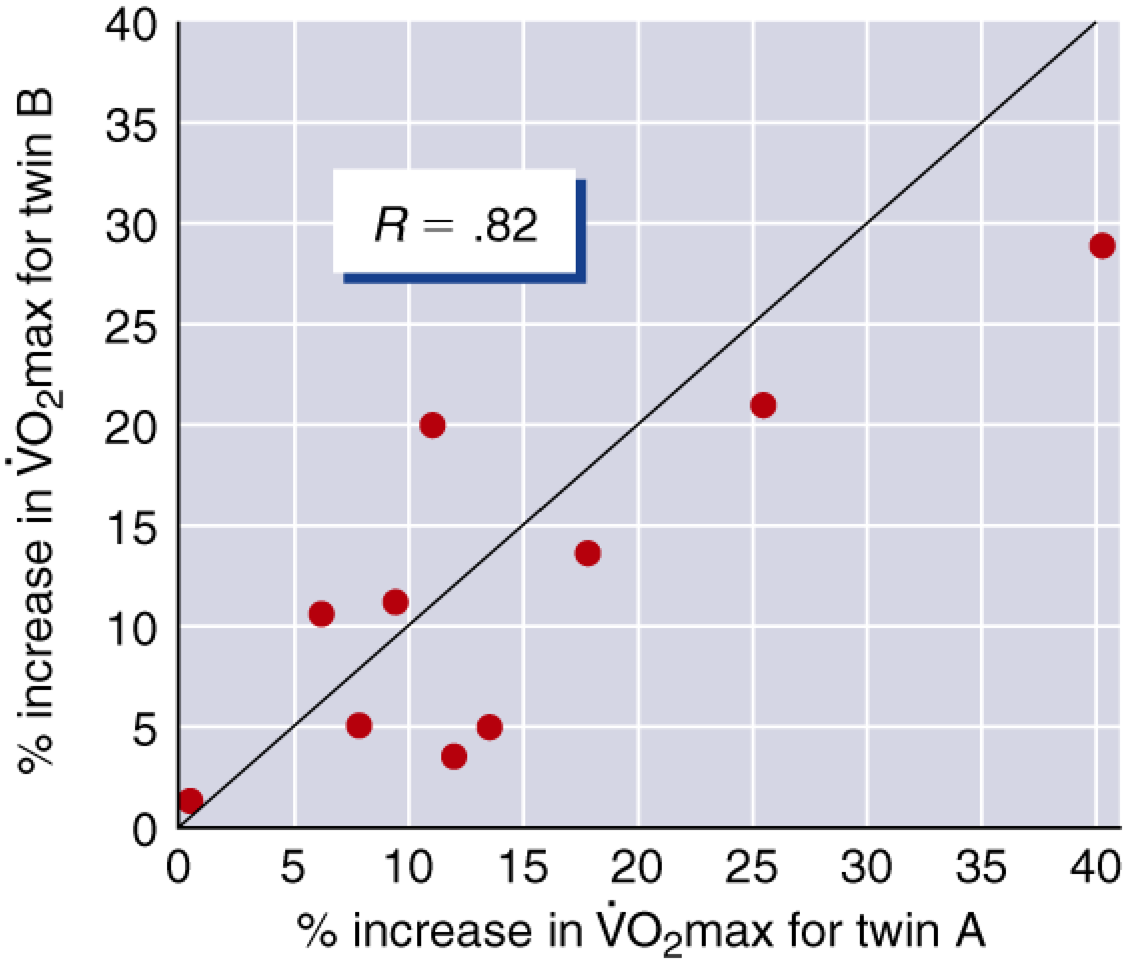
$\dot{V}O_2$MAX CHANGES AND AGE



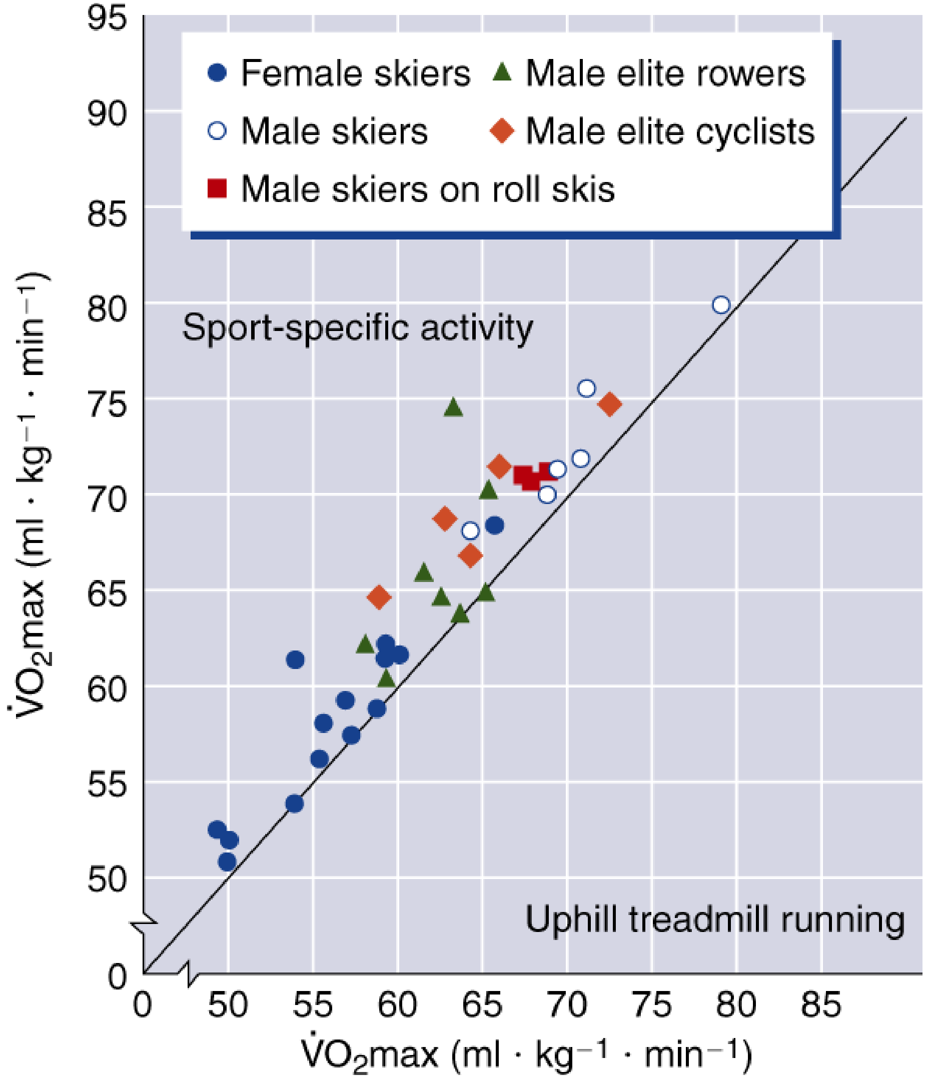
IMPROVEMENT IN $\dot{V}O_2$MAX WITH TRAINING



INCREASE IN $\dot{V}O_2$MAX FOR TWINS



$\dot{V}O_2$MAX AND SPECIFICITY OF TRAINING



Cardiorespiratory Endurance Training

- Major defense against fatigue which limits optimal performance.
- Should be the primary emphasis of training for health and fitness.
- All athletes can benefit from maximizing their endurance.

MODELING ENDURANCE PERFORMANCE