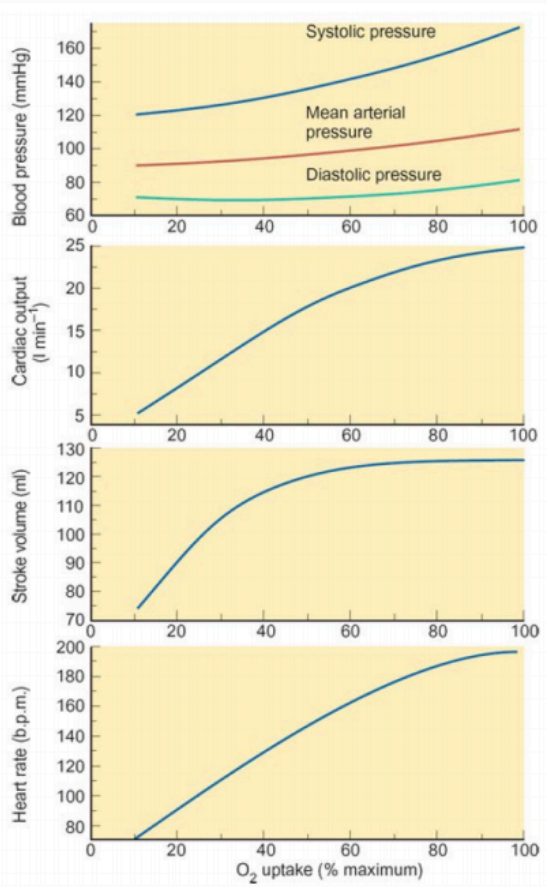
Cardiovascular Responses to Exercise

1) Meeting the Increased Energy Demand of Exercise – Cardiac Output, Heart Rate, Stroke Volume

Changes that occur during exercise that allow the cardiovascular system to increase blood flow to muscles:

- **Arterial pressure** INCREASES.
- **Cardiac output** (volume of blood, in L, pumped by the heart per minute) INCREASES.
- Cardiac output (CO) = heart rate (HR) x stroke volume (SV).
    - **Heart rate** (number of heart beats per minute) INCREASES.
    - **Stroke volume** (amount of blood pumped by the left ventricle per minute) INCREASES.



- **Heart rate** increases linearly.
- **Stroke volume** increases exponentially.
- However, eventually, at approximately 60% of VO2 max, stroke volume plateaus and therefore any further increases in cardiac output are due to increases in the heart rate.
- The increase in metabolic demand during exercise is thus met by an increase in cardiac output.
- **Cardiac output** (CO) is equal to the volume of blood pumped by the heart per minute, in L/min.
- In ***untrained and trained individuals***, resting CO is the same.
- In untrained individuals at maximal exercise, CO can reach 20L/min.
- In trained individuals at maximal exercise, CO can reach 40L/min.
- 4-fold and 8-fold increase in cardiac output following exercise.
- The capacity to exercise is **LIMITED** by ***CARDIAC OUTPUT***.

Autonomic Control of Heart Rate

- Heart rate is under tonic **parasympathetic (vagal) control at rest**.
- Heart rate increases with exercise or stress.
- ***Parasympathetic vagal tone*** is ***reduced*** and ***sympathetic tone*** is ***increased***.
- The parasympathetic nervous system neurotransmitter is acetylcholine, binds cholinergic receptors.
- The sympathetic nervous system neurotransmitter is noradrenaline, binds adrenergic receptors.

Parasympathetic NS
↓
Acetylcholine
↓
⇓ Heart Rate

Sympathetic NS
↓
Noradrenaline
↓
⇑ Heart Rate

Heart Rate and Training

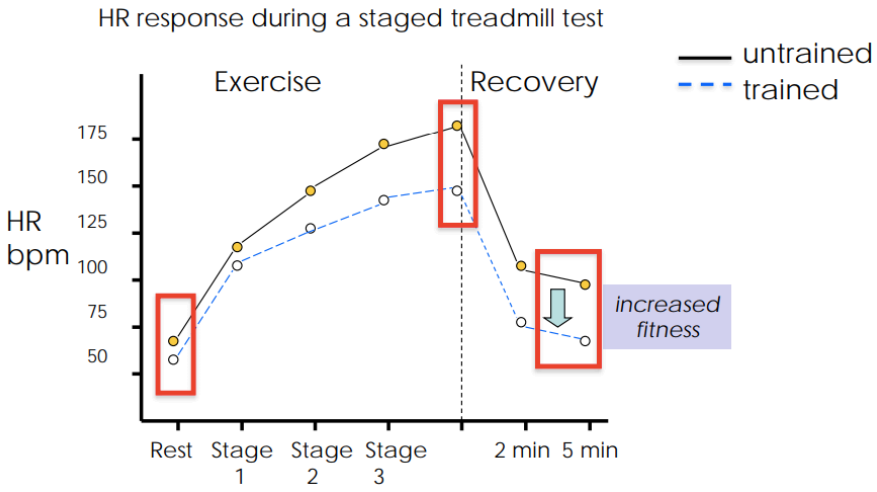
- With training, there is improved efficiency of cardiovascular system to pump blood (**increased stroke volume**).
- Heart needs less beats to provide oxygen with chronic exercise training.
- The ***resting heart rate is reduced in individuals after training***, less beats needed per minute.
- Thus, there is a greater filling time (end-diastolic volume is increased) → more blood pumped with each beat.
- **End-diastolic volume**: the volume of blood in the heart at the end of diastole (relaxation) and just before systole.
- ***Note that resting CO is the same*** in trained and untrained individuals, but heart rate is lower in trained.

Resting Heart Rate

- untrained person 60-80 bpm
- trained person 35-45 bpm
- elite athlete 25-40 bpm

Heart rate can be used to monitor improvements in fitness during CV training

- Note that ***maximal heart rate does not change*** with chronic exercise training.
- ***Maximal heart rate depends on an individual's AGE***. Maximal heart rate = 200 bpm - age.
- Sub-maximal heart rate changes with training however – trained individuals have a lower heart rate for the same workload compared to untrained individuals.
- Trained individuals have increased vagal input + decreased sympathetic input → ***sub-maximal heart rate lower***.
- Heart rate increases with exercise nonetheless both in untrained and trained individuals in order to increase the oxygen supplied to working skeletal muscles and tissues.



Sub-maximal heart rate decreases with chronic exercise training.
Heart rate increases nonetheless with an acute exercise bout.
Maximal heart rate is relatively unchanged with heart rate.

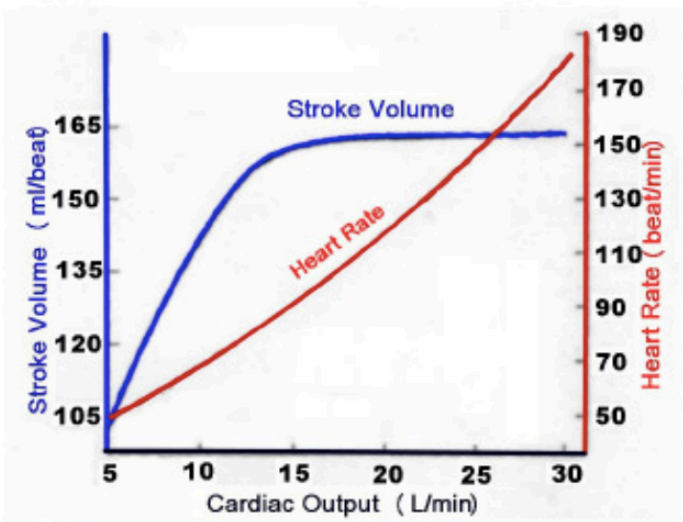
Stroke Volume and Training

- **Stroke volume**: the volume of blood ejected from the left ventricle per beat.
- **Systole**: contraction or pumping of the heart.
- **Diastole**: relaxation and refilling of the heart with blood.
- **End-systolic volume**: the volume of blood in the heart following systole.
- **End-diastolic volume**: the volume of blood in the heart following diastole.
- Stroke volume therefore is equal to end-diastolic volume – end-systolic volume.
- Thus, when end-systolic volume is higher (greater volume of blood in the heart after the heart contracts), the stroke volume will be smaller (as ESV is a larger value).

SV = EDV – ESV

At rest, untrained individuals have a lower SV than trained individuals, but higher HR. Therefore, CO = same.

- Stroke volume increases proportionately with increasing exercise <u>until around 60% of maximal exercise</u> (VO2 max), where it then plateaus.
- Increases in CO are therefore due to increases in heart rate after 60% VO2 max.



Approximate stroke volume and heart rate at different levels of cardiac output in a marathon athlete.

Stroke volume is influenced by:

1) Afterload
2) Preload
3) Venous return
    a. Skeletal muscle pump
    b. Respiratory pump*
    c. Venous dilation
4) Contractility
    a. Positive inotropic agents
    b. Negative inotropic agents

<u>STROKE VOLUME</u> is regulated by FOUR main factors, including: **afterload**, **preload**, **contractility** and **venous return**.

<u>Afterload</u> Influences Stroke Volume

MAP = CO x TPR

- **Afterload**: the amount of <u>resistance/load the heart must pump against</u> to eject blood.
- If the load is higher due to increased **mean arterial blood pressure** (MAP), then the <u>end-systolic blood volume</u> will be increased, as more blood will remain in the heart after systole. As stroke volume = EDV - ESV, then the stroke volume will be reduced. But this reduction is only slight; due to the increased MAP → greater venous ret.
- Therefore, <u>stroke volume is inversely proportionate to afterload</u> (when afterload is high, stroke volume is lower).
- Thus, increased afterload is concomitant with reduced stroke volume and therefore, reduced cardiac output.
- However, this is ***dampened in exercise due to vasodilation of the vessels***.
- **MAP decreases with chronic training** (still higher than rest), therefore afterload is decreased → ***slight*** fall in SV.
- At maximal exercise there is no change in mean arterial pressure.
- There is ***<u>increased vascular conductance and reduced vascular resistance</u> of the vessels*** during exercise.