

Cardiovascular and Respiratory Adjustments to Stationary Bicycle Exercise.

BACKGROUND:

The integration of cardiovascular and respiratory adjustments occurring in response to varying levels of metabolic activity is very important in maintaining whole body, physiological homeostasis. During exercise, chemoreceptors, baroreceptors, and proprioceptors activate medullary control systems that increase our pulmonary ventilation and cardiac output to ensure maximum oxygen delivery and waste removal to and from skeletal muscle tissue. Local metabolite and blood gas concentrations increase blood flow to active skeletal muscles via autoregulatory mechanisms – metabolic autoregulation of arteriolar radius and regulation of blood flow through capillary beds by precapillary sphincters. After periods of exercise, especially intense anaerobic activity, these reflex responses are maintained for a period of 5-20 minutes or longer as blood CO₂ levels, blood O₂ levels, and blood lactate concentrations are restored.

During this cycle we are conducting a class-wide study of cardiovascular and respiratory adjustments occurring in response to exercise. For each subject, blood pressure, heart rate, and ventilation will be recorded as the individual recovers from a period of exercise biking or running. We will now review some basic concepts related to these physiological parameters.

Blood pressure

Throughout the experiment you will measure blood pressure at various time points. Recall that systolic pressure is the pressure in the arterial system during ventricular contraction, or systole. Systolic pressure is largely a function of the strength of contraction of the ventricle and how much blood is forced into the large arteries by ventricular contraction. Thus, the systolic pressure is going to be greatly influenced by factors that increase stroke volume.

On the other hand, diastolic pressure is the blood pressure remaining in the arteries during ventricular diastole, or between beats. Diastolic pressure is largely a function of resistance to flow provided by arterioles further along the arterial tree. Thus, any factor that changes total peripheral resistance (TPR) will greatly affect diastolic pressure – an increase in TPR will cause an increase in diastolic pressure, while a decrease in TPR will cause a decrease in diastolic pressure. To clarify this important concept think through the following example.

The ventricle contracts and blood is forced into the arterial system. The peak pressure in the arterial system during ventricular systole is the systolic pressure. However, because of resistance to blood flow provided by arterioles (TPR) not all blood leaves the arterial system during the period of time the ventricle relaxes. Thus, there is some pressure in the arterial system during ventricular diastole – the diastolic pressure. In a second example the ventricle contracts with the same strength as above, but the radius of the arterioles in a number of vascular beds throughout the body has been increased – TPR is dropped. What happens to

systolic and diastolic pressures? The systolic pressure stays the same as before because it depends on the contraction of the ventricle. However, because a number of arterioles throughout the body have dilated (TPR decreased), more blood leaves the arterial system during ventricular diastole than during the first example. Thus, since there is less blood in arterial system during ventricular diastole, arterial pressure in the system during diastole – diastolic pressure – drops in relation to the first example.

After measuring blood pressures, you will be asked to calculate pulse pressures and mean arterial pressures. The pulse pressure is the difference between systolic pressure and diastolic pressure. As you can see from the above discussion, this value is a good indicator of the relationship between cardiac contractility and the TPR of the vascular system – for example, pulse pressure is inversely proportional to the overall TPR.

Mean arterial pressure (MAP) is the average pressure in the arterial system during one turn of the cardiac cycle. Because ventricular diastole is longer than ventricular systole, MAP is a time-weighted average value, computed by:

- $MAP = [2 * \text{diastolic} + 1 * \text{systolic}] / 3.$

Pulmonary ventilation

Throughout this experiment you will also monitor pulmonary ventilation, the movement of air in and out of the lungs. Ventilation of the lungs is accomplished by the rhythmic contraction of the diaphragm and external intercostal muscles. The activity of these muscles is in turn regulated by oscillating neural centers in the medulla and pons, the respiratory centers. Contraction of the diaphragm and external intercostals produces changes in intrapulmonary volume and thus changes in intrapulmonary pressure relative to atmospheric pressure – in response to these pressure changes, air flows in and out of the lungs to equalize pressure gradients.

In this experiment you will specifically monitor respiratory rate, tidal volume, and vital capacity. Respiratory rate (RR) is simply the number of breaths and individual takes per minute. The tidal volume (TV) is the amount of air inhaled or exhaled with each breath under resting conditions. An average value for tidal volume is 0.5 L – it can be increased to about 2.5-4 L per breath during or following vigorous activity. Changes in the tidal volume are accomplished by using the inspiratory reserve volume (deeper inhalations) or the expiratory reserve (forced expirations). The vital capacity (VC) is the maximal amount of air that can be expired after a maximal inspiratory effort – it represents the total volume of air that can be moved in and out in one forced breath (vital capacity) and ranges from 3.0 to 5.0 L. Finally, using respiratory rate and tidal volume values, you will be able to calculate minute ventilation (V_M) at various time points. Minute ventilation is the total amount of air that moves in and out of the respiratory tract in one minute – $V_M = RR \times TV$. V_M is 6 to 7 L/min at rest and can increase to 40-60 L/min or more during and after exercise.

We will indirectly monitor respiratory rates and tidal volumes throughout the experiment in two ways. We will use a pneumograph band strapped around the chest that allows us to monitor

respiratory movements. We will also use an air temperature sensor inserted in a spirometer mouthpiece that monitors air temperature patterns and thus respiration volumes and rates. The pneumograph band and the air temperature sensor recordings will be calibrated to air volumes by using a wet spirometry recording of tidal volume and/or vital capacity.

METHODS:

A. Preparation for PowerLab Data Collection

1. Get the computer data acquisition system ready to record data. Turn on the PowerLab unit, or check that it's on, and then log on to the computer. After the initialization checks launch the CHART 4.1 application, a software package that simulates a chart recorder.
2. Turn on three recording channels:
 - **Channel 1** receives input directly from a pulse sensor – a plethysmograph; this will give you a tracing of your subject arterial pressure.
 - **Channel 2** receives input from an air temperature sensor via a bridge amplifier – this sensor is inserted in a spirometer mouthpiece and is used to monitor airflow patterns and thus respiration volumes and rates.
 - **Channel 3** receives input from a pneumograph band (respiratory belt) that is wrapped around the subject's chest; as the subject breathes, respiratory movements resulting from chest expansion/recoil are recorded – these movements are used to calculate respiratory volumes and rates.

B. Experimental procedures

1. Choose two individuals from your group to be experimental subjects – the other members of the group will be responsible for conducting experimental procedures. First you will measure the subject's tidal volume and vital capacity using wet spirometry – these values are used to calibrate your ventilation data at later analysis. Enter these values in the subject data sheet provided.

2. Record baseline (Resting, pre-exercise controls) blood pressure and obtain a sample pulse and ventilation record for each individual.

- Measure blood pressure by auscultation using a sphygmomanometer
- To obtain a baseline ventilation and pulse tracing you need to attach the pneumograph band, the air temperature sensor, and the pulse sensor to your subject
 - Have the subject step onto the treadmill or sit on the stationary bike
 - Attach the pulse sensor to an index finger
 - Insert the mouthpiece containing the air temperature sensor in the subject's mouth; clip the nose with provided nose clips
 - Attach the pneumograph band at about the level of the solar plexus or across the upper chest – it should be tight enough that it won't slip out of place with vigorous breathing
 - When all transducers are in place, obtain a baseline recording of pulse and ventilation – also have the subject perform a few vital capacity maneuvers to make sure that your ventilation recording will not go off-scale with vigorous breathing – insert comment using the "Comments" feature of the software
 - Once above baseline recordings performed, turn off the CHART but leave your subject "wired". The subject can now start a light exercise routine

3. Light exercise routine

- a. Note the time. With CHART off but with all transducers in place (BP cuff on arm, pneumograph band around chest, airflow sensor ready, pulse sensor in index finger), have the subject pedal steadily at a moderate friction setting or run at an easy pace for 5 min.
- b. Immediately at the end of exercise, immediately measure blood pressure (Time 0) and start the ventilation and pulse recordings – quickly adjust pulse sensor, pneumograph band, and/or airflow sensor if needed. Keep these recordings going throughout recovery period. Measure BP at 1, 4, 8 and 12 minutes post exercise (Time 1, 4, 8, 12, respectively). Enter your data in the subject data sheet and SAVE your ventilation and pulse records – you will use it to calculate respiratory rates, tidal volumes, and heart rates after completing all experimental procedures. Have the second subject follow exactly the same procedures.

4. Heavy exercise routine.

- a. After complete recovery from the light exercise, record BP, and a brief period of ventilation and pulse resting data.
- b. Note the time. Have the subject pedal against a harder friction setting or run at a fast pace for 10 minutes – this should be heavy exercise, above 70% maximal. Follow procedures of part **3a.** above to record post-exercise recovery. Record for 12 min or longer until the subject is back to resting levels. Enter your data in the subject data sheet and SAVE your ventilation and pulse records – you will use it to calculate respiratory rates, tidal volumes, and heart rates after completing all experimental procedures.

4. Repeat method sections **B. 2 – 4** with a second subject

ANALYSIS:

1. Using your ventilation and pulse Chart recordings, count pulse rate and respiration rate (RR) for a 30 second interval (15 seconds before/after) around the 1, 4, 8, and 12 minute post exercise recovery time data points. Enter data in respective subject data sheet.
2. Use the wet spirometry volume calibration to convert all respiratory tidal volume (TV) measurements from trace movements or air temperature tracings to air volumes breathed (L). Compute average TV for a group of breaths around the 1, 4, 8, and 12 minute post exercise recovery time data points. Enter data in respective subject data sheet.
3. Compute respiratory minute volume (V_M , L/min) as $V_M = RR \times TV$ around the 1, 4, 8, and 12 minute post exercise recovery time data points. Enter data in respective subject data sheet.
4. Report systolic/diastolic blood pressures in mm Hg for rest and the 1, 4, 8, and 12 minute post exercise recovery time data points. Enter data in respective subject data sheet.
5. Compute pulse pressure and mean arterial pressure for rest the 1, 4, 8, and 12 minute post exercise recovery time data points. Enter data in respective subject data sheet.
6. Clean up your lab station – leave it like you found it.
7. Turn in subject data sheets – we will compute class averages and give you data for analysis and use in a lab assignment.