TEACHING HUMAN CARDIOVASCULAR AND RESPIRATORY
PHYSIOLOGY WITH THE STATION METHOD

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We have developed a station method to offer combined cardiovascular and respiratory physiology exercises all in one laboratory period during our medical physiology course. This laboratory was designed for first-year medical students in order to minimize equipment costs, maximize efficient use of both student and faculty time, and facilitate integration of basic cardiovascular concepts with those in respiratory physiology. We designed six stations for the students to evaluate: cardiovascular and respiratory responses to dynamic exercise, cold pressor reflex, postural influences and respiratory modulation of cardiovascular functions, forced expiratory maneuvers with inverted bell spirometers, forced expiratory maneuvers and maximal inspiratory maneuvers with electronic spirometers with and without obstruction, and respiratory muscle strength. Students worked in groups of two to four and were assessed by individual laboratory reports. Although we neglected to formally assess the impact on students of changes in laboratory design, students appeared to respond enthusiastically to the laboratory and prepared knowledgeable laboratory reports.

Key words: laboratory stations; cardiovascular experiments; respiratory experiments

With the recent emphasis on incorporating student-directed active learning in all levels of physiology, many programs have come to regret their shifts away from the use of laboratories for accomplishing some of the learning objectives in their courses. The dissolution of the laboratory component of many physiology courses has been the result of one or more of the following factors: lack of instructors for the laboratories, limited teaching laboratory space, few sets of available equipment, lack of support for supplies, lack of faculty time, lack of time in the curriculum, and a desire to avoid the use of animals in teaching laboratories. To overcome some of these difficulties and still be able to offer hands-on opportunities for student learning, we designed a station method (from a poster presented along with the Refresher Course for Teaching Cardiovascular Physiology at Experimental Biology 1999) that integrates both cardiovascular and respiratory physiology of normal humans into a single laboratory time period (the same as our three-hour lecture block). The six stations were designed for students to evaluate cardiovascular and respiratory responses to dynamic exercise, the cold pressor reflex, postural influences and respiratory modulation of cardiovascular functions, forced expiratory maneuvers with an inverted bell spirometer, forced expiratory maneuvers and maximal inspiratory maneuvers with an electronic spirometer with and without an obstruction, and respiratory muscle...
This station design for one of the laboratory experiences has been used for first-year medical students during our medical physiology course at the University of South Dakota School of Medicine. We briefly describe the design, learning objectives, and assessment of these stations.

**GENERAL DESIGN OF THE LABORATORY**

Medical physiology classes at the University of South Dakota School of Medicine have about 54 students. Laboratories are generally offered only three times during the five-and-a-half-month-long course. In this systems physiology approach, the integrated cardiovascular and respiratory laboratory has been scheduled to occur during the middle of the respiratory physiology section of the course, the section that immediately follows the cardiovascular section. The timing encourages the students to integrate the concepts they learned in cardiovascular physiology with those in respiratory physiology. This station approach to a physiology laboratory demonstrated efficiencies for the use of both resources and time. All of the six different stations offer educational opportunities for the students to learn concepts of cardiovascular and respiratory physiology using themselves as human subjects (Table 1). The time available for each laboratory session is three hours, and one-half of the class (27 students) participates in the laboratory at one time. For activities that are likely to be more time consuming, there are two experimental setups (i.e., two stations) available to be used. The costs of supplies for each station are minimal, with cardboard

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**TABLE 1**

The six stations

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Measurements</th>
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<tbody>
<tr>
<td><strong>Station 1: Cardiovascular and respiratory responses to dynamic exercise</strong></td>
<td>Blood pressure, heart rate, tidal volume &amp; frequency of breathing</td>
</tr>
<tr>
<td>While resting upright standing</td>
<td>Blood pressure, heart rate, tidal volume &amp; frequency of breathing</td>
</tr>
<tr>
<td>During exercise to 75% maximal</td>
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</tr>
<tr>
<td>Heart rate</td>
<td></td>
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<td>First 10 min postexercise</td>
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<tr>
<td><strong>Station 2: Cold pressor test</strong></td>
<td>Blood pressure, heart rate, right hand skin blood flow</td>
</tr>
<tr>
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<td>Blood pressure, heart rate, right hand skin blood flow</td>
</tr>
<tr>
<td>Left hand in ice water</td>
<td>Blood pressure, heart rate, right hand skin blood flow</td>
</tr>
<tr>
<td>Recovery</td>
<td>Blood pressure, heart rate, right hand skin blood flow</td>
</tr>
<tr>
<td><strong>Station 3: Postural influences &amp; respiratory modulation of cardiovascular function</strong></td>
<td>Blood pressure, heart rate, tidal volume &amp; frequency of breathing</td>
</tr>
<tr>
<td>While resting supine</td>
<td>Blood pressure, heart rate, tidal volume &amp; frequency of breathing</td>
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<tr>
<td>Loading the atrial volume receptors (raising the legs)</td>
<td>Blood pressure, heart rate, tidal volume &amp; frequency of breathing</td>
</tr>
<tr>
<td>After lowering the legs</td>
<td>Blood pressure, heart rate, tidal volume &amp; frequency of breathing</td>
</tr>
<tr>
<td>While performing a Valsalva maneuver</td>
<td>Blood pressure, heart rate, tidal volume &amp; frequency of breathing</td>
</tr>
<tr>
<td>While resting supine</td>
<td>Blood pressure, heart rate, tidal volume &amp; frequency of breathing</td>
</tr>
<tr>
<td>Gravity-induced blood pooling by quickly standing</td>
<td>Blood pressure, heart rate, tidal volume &amp; frequency of breathing</td>
</tr>
<tr>
<td><strong>Station 4: Forced expiratory maneuvers with inverted bell spirometer</strong></td>
<td>From volume-time curve – forced vital capacity (FVC), forced expiratory volume in first second (FEV1.0), forced expiratory flow from 25% VC to 75% VC (FEF25-75%)</td>
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<tr>
<td>Forced expiratory maneuver</td>
<td>FVC, FEV1.0, FEF25-75%, peak inspiratory and expiratory flows</td>
</tr>
<tr>
<td><strong>Station 5: Forced expiratory maneuvers with electronic spirometer</strong></td>
<td>FVC, FEV1.0, FEF25-75%, peak inspiratory and expiratory flows</td>
</tr>
<tr>
<td>Normal forced expiratory maneuver &amp; maximal inspiratory maneuver</td>
<td>FVC, FEV1.0, FEF25-75%, peak inspiratory and expiratory flows</td>
</tr>
<tr>
<td>Forced expiratory maneuver &amp; maximal inspiratory maneuver with airway obstruction</td>
<td>FVC, FEV1.0, FEF25-75%, peak inspiratory and expiratory flows</td>
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<tr>
<td><strong>Station 6: Tests for respiratory muscle strength with a bugle</strong></td>
<td>Maximal inspiratory pressure</td>
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<tr>
<td>Maximal inspiration</td>
<td>Maximal inspiratory pressure</td>
</tr>
<tr>
<td>Maximal expiration</td>
<td>Maximal expiratory pressure</td>
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mouthpieces and recording paper being the predominant costs.

Students are asked to work in pairs or groups of four with at least one of the students serving as the subject at each station. During the rotations, each student serves as both an observer/recorder and an experimental subject. Student pairs rotate from station to station until all of the activities have been completed. Senior graduate students and teaching faculty members are available to assist with the stations as needed by the students. In advance of the laboratory session, students are given handouts that introduce the activities. Brief laboratory reports are required from the students to assess their learning of the basic concepts of cardiovascular and respiratory physiology.

Station 1: cardiovascular and respiratory responses to dynamic exercise. The learning objectives of this activity are to evaluate the combined physiological responses of the cardiovascular and respiratory systems to dynamic exercise on either a stationary bicycle or a cross-country ski apparatus. The activities to be done at station 1 are expected to take ~20 min to complete. Two complete stations are available to the students, and students are encouraged to conduct the experiment in pairs.

The experimental setup for these activities includes recording of data on a computer from measurements of blood pressure by sphygmomanometry, heart rate by pulse, and respiratory movements by a Piezo Trace respiratory effort transducer (Grass Instruments, Quincy, MA). Baseline measurements are first taken while the subject is resting quietly on the exercise machine. Then the subject exercises until they reach 70–80% of their predicted maximal heart rate (for males, 220 – age; for females, 226 – age). Shortly after reaching that point, subjects stop exercising to make measurements. While resting, the students are encouraged to continue recording for up to 10 min postexercise. This allows the students to observe not only the peak cardiovascular and respiratory adjustments to dynamic exercise but also the recovery of cardiovascular and respiratory function following a short burst of exercise.

Station 2: cold pressor test. The learning objectives of this activity are to introduce the student to the cardiovascular responses to exposure to cold. An appreciation of these responses can be very helpful to the students in understanding the effects of cold-air exposure in anginal and other cardiovascular patients. The activities to be done at station 2 are expected to take ~20 min to complete. One station is available, and the students are encouraged to work in pairs. The students compare the blood pressure and heart rate responses to immersion of a hand in cold water and the effects of cold temperature on skin blood flow. For this activity, blood pressure is measured by sphygmomanometry and heart rate by palpation, and skin blood flow is measured continuously with a laser Doppler flowmeter borrowed from a research laboratory. Variables are measured at rest while the subject is seated quietly at a table. Right hand blood flow is monitored while the left hand is placed in ice water for a short time. Blood pressure and heart rate should be measured quickly in the right arm, because the ice water can be extremely uncomfortable for some subjects. After recovery, pulse and blood pressure in the right arm are measured again. Changes in skin blood flow are expressed as percent change from control [(experimental blood flow – control blood flow)/control blood flow × 100].

Station 3: postural influences and respiratory modulation of cardiovascular functions. The learning objectives at station 3 are to measure and analyze the physiological responses of the cardiovascular and respiratory systems to three different common interventions: 1) loading the atrial volume receptors, 2) performing a Valsalva maneuver, and 3) gravity-induced blood pooling. The activities to be done at station 3 are expected to take ~40 min to finish. The experimental setup for these activities includes recording on a Grass polygraph borrowed from a research laboratory, the cardiovascular measurements of blood pressure by sphygmomanometry, and heart rate by EKG or pulse. The subject’s tidal volume of breathing is measured throughout the experiment with a Piezo Trace respiratory effort transducer. Minute ventilation [tidal volume (volume/breath) × breathing rate (breaths/min)] is calculated. Because of the time demands for these activities, two complete versions of station 3 are available to the students, and students are encouraged to make the measurements in a group of four students instead of as pairs.
The subject begins by resting quietly in a supine position. For all three interventions, blood pressure, heart rate, and respiratory rate are measured immediately before and after return to resting as control data and during the intervention as experimental data. Changes in cardiovascular and respiratory variables are attributed to both direct effects (i.e., via changes in venous return) and indirect effects (i.e., via pulmonary and/or cardiovascular reflexes).

The intervention for atrial baroreceptor loading involves an assistant raising the subject’s legs to an angle of 45° off the table. To avoid the complicating effects of the skeletal muscle blood pump, it is important that the subject not perform tonic contraction of the leg muscles. Accordingly, a helper is used to raise and lower the legs, and the subject is instructed not to exert muscle activity. After resting measurements and these “loading” measurements, controls are again measured with the legs back in their original supine position. Systolic, diastolic, and mean [diastolic + 1/3 (systolic-diastolic)] blood pressures are recorded for each period. Respiratory frequency (breaths/min), nominal tidal volume, and minute ventilation are derived from the respiratory effort tracings.

The intervention for the Valsalva maneuver involves the subject expiring against a closed glottis and thus increasing intrathoracic pressure. The observer must take the pulse (EKG) and blood pressure quickly during the Valsalva maneuver, because the maneuver is difficult to maintain for an extended time. Visual observations can include signs of decreased venous return like distended jugular veins, decreased emptying of veins in a raised hand, etc. After the Valsalva maneuver, the subject should rest supine for ≥10 min before the next maneuver is performed.

Unloading the baroreceptors is accomplished by having the subject move quickly from a supine to a standing position. Although both blood pressure and heart rate are monitored, a major focus during this maneuver is the continuous recording of the EKG that allows assessment of transient responses in heart rate.

**Station 4: forced expiratory maneuvers with inverted bell spirometer.** The learning objectives of this activity are to practice basic forced expiratory maneuvers and to calculate the standard parameters analyzed by pulmonary function testing in a clinical setting. The activities to be done at station 4 are expected to take ~15 min to complete. Two complete stations are available to the students, and students are encouraged to conduct the experiment in pairs. The experimental setup for this activity is to record volume-time curves during a forced expiratory maneuver on an inverted bell spirometer.

The forced expiratory maneuver consists of a subject inhaling maximally to total lung capacity and then blowing all the air out of the lungs to residual volume as fast and as forcefully as possible. After such a maneuver, the volume (ΔV) measured between maximal inspiration and maximal expiration is the forced vital capacity (FVC). The volume exhaled in the first second is the forced expiratory volume (FEV₁₀). The ratio of FEV₁₀ to FVC (FEV₁₀/FVC), expressed as a percentage, can be interpreted to see whether the normalized FEV₁₀ is abnormally low. The flow rate in the middle half of the FVC can be calculated as the slope of the line connecting 25% FVC and 75% FVC. This is called the forced expiratory flow (FEF₂₅₋₇₅%). These parameters can be used to assess the severity of impairment to ventilation for the individual. Lung function values are influenced by height, age, and sex. Consequently, to compare pulmonary function among different individuals, percent predicted values can be determined from the following equations (A = age in yr, and H = height in cm) (3):

**Forced vital capacity (FVC)**

- males: 0.0844(H) − 0.0298(A) − 8.782
- females: 0.0427(H) − 0.0174(A) − 2.900

**Forced expiratory volume in the first second (FEV₁₀)**

- males: 0.067(H) − 0.0292(A) − 6.515
- females: 0.0309(H) − 0.0201(A) − 1.405

**Forced expiratory flow from 25–75% vital capacity (FEF₂₅₋₇₅%)**

- males: 0.058(H) − 0.036(A) − 4.518
- females: 0.021(H) − 0.034(A) + 1.128
Station 5: forced expiratory maneuvers and maximal inspiratory maneuvers with an electronic spirometer (with and without an obstruction). The learning objectives of this activity are to evaluate lung function via comparison of both volume-time curves and flow-volume loops under normal conditions and a simulated obstruction, and to compare these measurements with the values calculated from the plot of the forced expiratory maneuver in station 4. The activities to be done at station 5 are expected to take ~20 min to complete. Two complete stations are available to the students, and students are encouraged to conduct the experiment in pairs. The experimental setup for these activities involves using an electronic spirometer (FlowMate Plus, Spirometrics Medical Equipment, Auburn, ME) to record volume-time curves and flow-volume loops from maximal inspiratory and forced expiratory maneuvers. The computer in the spirometer automatically calculates the measured, predicted, percent predicted, and percent variability (between tests) values for FVC, FEV₁₀, FEV₁₀/FVC, FEF₂₅–₇₅%, and numerous other values. In addition, a patient summary report gives an analysis of the risk of chronic obstructive pulmonary disease, an analysis of the risk of disease if smoking is stopped, and the estimated lung age of the subject. After the recording of a forced expiratory maneuver and summary for the normal condition, a cork with a small hole is inserted into the mouthpiece, and the student repeats the maneuver while breathing in and out through the cork. This simulates a fixed extrathoracic obstruction to give the student an appreciation of the effects of an obstructive pulmonary disease. The changes can easily be seen by analyzing the flow-volume loops.

Station 6: tests for respiratory muscle strength with a bugle. The force generated by the respiratory muscles is a measure of respiratory muscle strength [maximal inspiratory and expiratory pressures (MIP, MEP)] and can be used to diagnose diseases that affect respiratory muscle function. The apparatus used to evaluate these pressures is called a bugle. The bugle was custom designed for the Mayo Clinic and is a stainless steel cylinder of 32 cm in diameter with an enclosed end and an open end for inserting a cardboard mouthpiece. Near the closed end is an exit port attached to a three-way metal stopcock. The stopcock is attached by tubing to one of two dials (a standard pressure gauge and a vacuum gauge) that are attached to the cylinder via a support. To determine MIP, one should exhale maximally and then, while making a maximal inspiratory maneuver, suck through the mouthpiece of the bugle for at least 3 s. The highest value on the pressure gauge during the maneuver is recorded as the MIP. To determine MEP, one should inhale maximally and then exhale maximally and very forcefully into the bugle for 3 s and record the maximal pressure value. Measured values can be compared with predicted values from the equations below (A = age in yr) and the percent predicted values can be calculated (1).

\[
\text{lower limit of normal:} \\
\text{male MIP} = 143 - 0.55(A) \\
\text{male MEP} = 268 - 1.03(A) \\
\text{female MIP} = 104 - 0.51(A) \\
\text{female MEP} = 170 - 0.53(A)
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ASSESSMENT OF STUDENT LEARNING

For assessment of learning, individual students write laboratory reports, including analysis and interpretation of results from the activities at each of the stations. The cardiovascular component of the report summarizes the activities of stations 1–3 by use of a standard format that stresses accurate recording of data, complete discussion, and interpretation of findings. Although accurate recording of data is evaluated, greater emphasis is placed on correct interpretation and explanation of the findings by use of basic physiological principles. Guidelines for analysis of the results from the cardiovascular stations are based on the following questions.

1) Were the heart rate and blood pressure changes opposite or parallel?
2) Which response came first?
3) What happened to the mean arterial pressure?
4) Can you explain the changes in diastolic pressure, systolic pressure, and pulse pressure?
5) What happened to heart rate, tidal volume of breathing, and breathing frequency?

6) Are these responses due to direct effects of the intervention, or are these secondary (indirect) effects caused by the response of the body to the initial perturbation (reflex effects)?

For each intervention, the report includes a description of the predicted response (i.e., blood should pool in veins upon standing, baroreceptor reflex should increase heart rate and vascular resistance to maintain blood pressure); a description of the observed response (i.e., heart rate went up, systolic pressure dropped, and diastolic pressure increased, with a net decrease in mean pressure); a brief physiological explanation for both the predicted and observed responses (i.e., predicted a reflex increase in sympathetic activity to increase heart rate and peripheral resistance sufficiently to maintain pressure. The observed decrease in mean pressure suggests that sympathetically mediated increases in peripheral resistance and heart rate were unable to fully compensate for excessive pooling of blood in the veins and the decreased venous return).

The report for the respiratory component (stations 4-6) is designed to compare and contrast the results of the two different kinds of spirometers, compare one’s own pulmonary function results with predicted values, and compare normal pulmonary function with pulmonary function variations during the simulation of an obstructive lung condition. Thus (for the inverted bell spirometer) students report the measured values, corrected values (measured volumes × 1.07 to adjust for the original gases in the lungs being at 37°C instead of at room temperature), predicted values, and percent predicted values for the FVC, FEV1.0, FEF25–75%, and FEV1.0/FVC. For the electronic spirometer, the students report the corrected measured, predicted, and percent predicted values for FVC, FEV1.0, FEF25–75%, FEV1.0/FVC, and peak expiratory flow (from the flow-volume loops) and the same values for the maneuver with the cork. Students are asked to analyze why they may have gotten different values for the measurements from the two different types of spirometers. Students are also asked to evaluate and explain the differences on both the volume-time curves and the flow-volume loops between their normal values and those with the cork in the mouthpiece. The student reports for respiratory muscle strength include measured, predicted, and percent predicted values for maximal inspiratory and maximal expiratory pressures. The students are asked to evaluate their own pulmonary function by answering the following questions. What do these tests tell you about your own pulmonary function? How do you explain your results? Finally, the students are asked to list the changes in the values for a forced expiratory maneuver (FVC, FEV1.0, FEV1.0/FVC (%), FEF25–75%) that could be used to predict whether the patient has an obstructive or a restrictive type of lung disease.

CONCLUSION

We chose to design a station method for offering hands-on activities to first-year medical students in an integrated laboratory with cardiovascular and respiratory physiology experiments. Some of the stations that we use involve rather costly pieces of equipment, like electronic spirometers, polygraph recorders, EKG amplifiers, Piezo Trace respiratory effort transducers, and laser Doppler flowmeters. Numerous units for these activities are hard to justify in the institutional budgets for limited use in teaching laboratories. Mackin and Williams (4) dealt with similar problems for using hands-on science activities in high school science courses with less than adequate resources. They described several possibilities, including take-home laboratory activities, paper-and-pencil laboratory activities [i.e., a good example for physiology would be the virtual rat experiments designed by Odenweller and colleagues (5)], and various activities offered as lab stations. Students worked in small groups in multiple activities at stations (some of which required specialized equipment). Thus the station approach to offering laboratory activities appears to be a good one for conservation of limited equipment, resources, and time as well as for promoting student-student interactions.

Fisher and colleagues (2) designed and tested the teaching of neuroanatomy to medical students by means of self-instructional laboratory stations. They evaluated both the effectiveness of the laboratory
presentation of the concepts for content mastery and the acceptance of this form of laboratory by the students. Their students were enthusiastic about the station format and had positive attitudes with respect to the subject matter. Unfortunately, during the evolution of our laboratory exercises, we neglected to survey students about their experiences. As long as there were enough complete stations available for the efficient use of their time, our students seemed to rotate through the activities enthusiastically, have a variety of experiences, and ably interpret cardiovascular and respiratory physiology in their subsequent reports. The laboratory was scheduled at a time when the students had already learned some of the concepts of cardiovascular and respiratory physiology. The opportunity to integrate systems and the added relevance to both practical and clinical knowledge appeared to enhance learning for our students. Indeed, the students were generally very excited to put some of their theoretical knowledge into practice in performing and interpreting their experiments. For further information about the equipment, the design of the stations, and the handouts used by the students, contact Dr. Barbara Goodman.

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